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AN ISLAMIC RESPONSE TO GREEK ASTRONOMY

Kitāb Taʿdīl Hayʾat al-Aflāk
of Ṣadr al-Sharīʿa

EDITED WITH TRANSLATION
AND COMMENTARY BY

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To the memory of my father
and for my mother
with love and gratitude

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INTRODUCTION

As early as the ninth century, Muslim astronomers started refining the Ptolemaic astronomy which, by this time, had been fully adopted as the framework of their research.[1] Already, in the early part of this century, refinements were based on improved observational techniques, and included a variety of phenomena such as the length of the seasons, the solar equation, mean motion parameters, and many others.[2]

These activities generated a more theoretical appreciation of Ptolemaic astronomy. The few centuries that followed witnessed a much closer examination of the theoretical foundations of this astronomy, and culminated in the famous eleventh-century treatise of Ibn al-Haytham called *Doubts on Ptolemy*,[3] in which the whole range of Ptolemaic astronomy was put into question.

Although Ptolemaic astronomy could predict the positions of planets with reasonable accuracy, it nevertheless was found objectionable because the models of this astronomy did not always conform to axioms concerning the supposed nature of the motion of the heavenly bodies. The problem of the equant point, for example, required that a sphere should move uniformly around an axis which does not pass through its own center. This is in clear violation of the principle of uniform circular motion.

As far as we know, such discrepancies were first discussed in great detail by Ibn al-Haytham in the text just mentioned, but no actual solutions seem to have been produced by him. Others took the project a step further and devoted their research to the construction of alternative models to replace the Ptolemaic ones. This tradition engaged many of the more famous Muslim astronomers from the eleventh century onwards. In the Islamic West several rather unsuccessful attempts were made to identify these problems and resolve them.[4] In the East, however, similar attempts were much more fruitful, and the exposition of the problems of Ptolemaic astronomy was later followed by a series of substantial and workable solutions. The thirteenth century was a high point for this eastern tradition, and the works

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[1] See Kennedy, 1983, p. 44.

[2] See Kennedy, 1983, p. 45.

[3] See Sabra and Shehabi.

[4] See, for example, Biṭrūjī; also, for a more general survey of these activities see, Saliba, To Appear, pp. 42-5, where an overview of the contributions of such astronomers as Jābir Ibn Aflaḥ (c. 1150 A.D.), Al-Biṭrūjī (c. 1200 A.D.), and Ibn Rushd (d. 1198 A.D.) is given.

of ʻUrḍī[5] (d. 1266 A.D.), Ṭūsī[6] (d. 1274 A.D.), and Shīrāzī[7] (d. 1311 A.D.), of the Maragha school,[8] set the tone for astronomical research in the following two centuries, and perhaps until the eventual demise of Ptolemaic astronomy.

The tradition which became dominant with the works of the Maragha school carried on to the fourteenth and fifteenth centuries. The culmination of this activity is best exemplified by the work of the fourteenth-century Damascene astronomer Ibn al-Shāṭir, who produced models which incorporated uniform circular motions, and at the same time corresponded to the observed physical phenomena.[9] Many of the devices embedded in the above models, as well as in the models of the Maragha school scholars, were also adopted in the sixteenth-century models of Copernicus. This seems to indicate that the above scientific activity was continuous and not sporadic, and that its impact was not restricted to the Muslim East, but apparently reached the Latin West, as well.

That this tradition continued in the East is further confirmed in the case of a contemporary of Ibn al-Shāṭir, namely ʻUbayd Allāh b. Masʻūd b. Tāj al-Sharīʻa Maḥmūd b. Ṣadr al-Sharīʻa (al-Akbar, al-Awwal) Aḥmad b. Jamāl al-Dīn ʻUbayd Allāh al-Maḥbūbī al-ʻUbādī al-Bukhārī al-Ḥanafī, known as Ṣadr al-Sharīʻa al-Thānī (hereafter Ṣadr, d. 747 A.H./1347 A.D.), who worked independently of the former in the Central Asian city of Bukhārā. Ṣadr's astronomical work represents an ongoing revision of Ptolemaic astronomy. In that context, he undertook to correct the works of two of his predecessors, namely Ṭūṣī and Shīrāzī. The models of the last two were developed in their two respective works, the *Tadhkira* and the *Tuḥfa*. Ṣadr took it upon himself to solve the problems they did not tackle, and to supply answers to the subtleties they did not address.

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5 On the work of ʻUrḍī see Saliba, 1990, pp. 30-43.

6 On the work of Ṭūsī see De Vaux, Hartner, 1969, and *Tadhkira*.

7 On the work of Shīrāzī see Kennedy, 1983, pp. 84-97.

8 Hulagu of the Ilkhānid dynasty commissioned Naṣīr al-Dīn al-Ṭūsī to establish and direct an observatory at Maragha, to which he invited many Muslim and non-Muslim astronomers. Among these were Mu'ayyad al-Dīn al-ʻUrḍī who came from Syria, and Quṭb al-Dīn al-Shīrāzī. These three scholars produced a number of works which dealt with the problems of Ptolemaic astronomy, and proposed a number of significant solutions to these problems. Moreover, a major part of the discussion at this stage was devoted to questioning the adequacy of the newly proposed models.

On the history of this observatory see Sayili, 370-3.

9 On Ibn al-Shāṭir see Kennedy and Gahnem; also see Kennedy, 1983, pp. 50-83.

THE PRESENT STUDY

The subject of the present study is *Kitāb Ta'dīl Hay'at al-Aflāk* (*The Adjustment of the Configuration of the Celestial Spheres*) of Ṣadr al-Sharī'a al-Thānī. The work is the third section of a three-part encyclopaedic survey of the exact sciences entitled *Ta'dīl al-'Ulūm* (*The Adjustment of the Sciences*).[10] This encyclopaedia starts with logic, proceeds through theology, and ends with astronomy. It was written in Bukhārā, and was finished shortly before the death of its author.

This work of Ṣadr is written in the traditional form of a commentary, where he gives his own text and then comments on the same. As is usual in such commentaries, the text is separated from the comments by the classical notation: a sentence preceded by the Arabic *mīm* (short for *matn*) refers to the text, whereas the latter *shīn* (for *sharḥ*) introduces the comment to that specific text. As a result the work became voluminous, reaching some seventy densely written folios. Moreover, the letters are sometimes missing or confused, and hence it is not always clear whether a certain section is part of the text or the commentary.

In order to appreciate Ṣadr's contribution to astronomy, it was thought advisable to separate the two stages of Ṣadr's production: the early stage when he produced the text, and the later stage when he wrote the commentary on his own work. In this book I undertook to study the first stage. Therefore, I had to separate the text from the commentary, and to produce an edition, a translation of, and a commentary on the text obtained therefrom. Ṣadr's commentary was used at this stage to inform my understanding of the original text, and the ideas discussed in it are reflected in the commentary produced in this book. In the future I plan to produce a critical edition of Ṣadr's whole work, including his own commentary.

THE MANUSCRIPTS

Of all the known manuscripts of Ṣadr al-Sharī'a's work *Kitāb Ta'dīl Hay'at al-Aflāk* (fourteen in number), six were made available for this study.[11] However, after studying those six, it became quite apparent that the language of the text itself was rather clear, and the few problems that remained relate to the technical understanding of the contents only. Since

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[10] For reference to this work see Brockelmann, vol. II, pp. 277-9, and Suppl. II. pp. 300-1; Dujaylī vol. II, p. 162; Ḥājī Khalīfa, vol. II, p. 315; Kaḥḥāla, vol. VI, p. 246; Luknawī, p. 94; Suter, # 404; Ṭāshkoprūzāde, vol. II, p. 182; Zarkalī, vol. IV, p. 354; and Zaydān, vol. II, p. 239.

[11] The present author wishes to express his gratitude to those librarians who cooperated with him by supplying microfilm copies of the MSS in their possession.

the main purpose at this stage was restricted to the appreciation of Ṣadr's contribution to astronomical research, it was thought that the available MSS can now be used to produce the working edition presented here.

1) *A* is a British Museum Manuscript[12] designated by the Arabic letter *alif* in the Arabic edition, but retained for the translation and commentary. This MS is kept in the Oriental collection in the British Museum under the number Add 7484, and it comprises the last section of Ṣadr's *T'adīl* (*The Adjustment of the Sciences*) only. The title page, however, mentions the general title of the *T'adīl*, as well as the author's name, and includes two ownership signatures. Only the year 1015 (A.H. = 1606/07 A.D.) can be identified from the first signature, while the second signature includes the following verse of poetry: "It should suffice that people later say about what you own, this was at one time owned by *fulān*." Immediately after that, the following curious signatures appears: "the female slave (*'abda*) of Ḥāj Muḥammad b. 'Umar, may God forgive both of them." The year 1165 (A.H. = 1751/52 A.D.) is written next to the latter name.

The manuscript comprises 70 folios numbered from 1 to 70. The handwriting is clear, and includes the usual occasional corrections in the margins of the manuscript. The manuscript is also supplied with diagrams, which are not always clear or correct, although the text supplies ample leads for reconstructing them.

The colophon identifies the scribe as Aḥmad b. Sirāj al-Dīn al-Ghimdiwānī who finished copying the text in Bukhārā "the city of Uleg Beg" (d. 1449) around the middle of Rajab of the year 823 (A.H. = 1420 A.D.).

Being the clearest of the six manuscripts, although not the earliest, this manuscript was used as a base copy, and the text of the English translation is referred to it.

2) *B* denotes the first Berlin MS[13] in the translation and commentary, and is designated with the Arabic letter *bā'* in the edition. The MS is kept in the Staatsbibliothek Preussischer Kulturbesitz under the number 5096-Lbg. 394, and it includes the complete work of Ṣadr. The third section alone was used for this edition. Its title page has several remarks in addition to two titles: the first title is simply *Ta'dīl al-'Ulūm*, while the second says: "this is the commentary on *Ta'dīl al-'Ulūm* by Ṣadr al-Sharī'a, in the hand of one of his students who copied it during the lifetime [of the author], may his secret be sanctified." This dating of the manuscript is in conflict with the signature of the scribe at the end which states that the writing was finished in Rabī' al-Ākhir of the year 758 (A.H. = 1357 A.D.), some eleven years after the death of Ṣadr al-Sharī'a. An ownership signature is not clear and might

[12] For a catalogue reference to this MS see Catalogus Museo Britannico, # 400.
[13] For a catalogue reference to this MS see Ahlwardt, p. 432.

have the year 1237 (A.H. = 1821/22 A.D.) written next to it. The remaining remarks on this title page refer to the folio numbers where some of the questions discussed in the accompanying text are identified.

The MS of Ṣadr's complete works comprises 243 folios. The book on astronomy starts at folio 184, thus occupying a total of 58 folios. The handwriting of this manuscript is not very clear, and no corrections appear in the text or margins, indicating that the copy was not collated with the original. As a result it is considered to be inferior to MS *A* mentioned above. Moreover the diagrams are sketchy and unreliable.

The name of the scribe is mentioned at the end of the manuscript, together with the above date, and the usual doxology. He was Ḥusayn b. Muḥammad, otherwise unknown to the present author. This MS is the earliest of the six manuscripts, and according to manuscript *H* below, which was copied from it, the present manuscript was written by a student of Ṣadr.

3) *G* indicates the second Berlin MS,[14] and is designated by the Arabic letter *jīm* in the edition. It is kept in the Staatsbibliothek Preussischer Kulturbesitz under the number 5683-Lbg. 144, and includes the last section of Ṣadr's three volume work which concerns us here. Its title page contains an ownership signature, the title "*Ta'dīl al-'Ulūm*, by the honorable master 'Ubayd Allāh b. Mas'ūd b. Tāj al-Sharī'a," (despite the fact that the MS includes the third book of the collection only, and not all three books), and the title of a Persian treatise on "*The Extraction of the Sine of One Degree*" written in a different hand.

The relevant part of the MS comprises 65 folios. The handwriting is clear and the MS contains a few copyist's corrections on the margins. Moreover, the diagrams are not lettered, and the entries to the tables are not filled in. For that reason, this MS too could not be used as a basic copy for the edition.

Although this MS has a colophon, in reality it omits the last paragraph of Ṣadr's work in which he mentions the composition date. Instead, the colophon simply contains the name Aḥmad al-Kashmarī, and the date of copying as Jumādā al 'Ūlā of the year 846 (A.H. = 1442 A.D.).

4) *W* refers to the Vienna MS[15] and is designated by the Arabic letter *fa'* in the edition. The MS is kept in the Austrian National Library in the Oriental Manuscript Collection under the number Wien 7. It has no title page, and neither the name of the scribe nor the date of copying are mentioned in the colophon. On the other hand, the handwriting is beautiful and clear, and the diagrams are neat, although not necessarily accurate. In addition, there are several copyist's corrections and comments made on the margins of the manuscript. The elegant appearance of the MS, however, does

[14] For a catalogue reference to this MS see Ahlwardt, p. 165.
[15] For a catalogue reference to this MS see Flugel, vol. XI, p. 13.

not make it any more reliable than the one chosen for the base text, because it still contains several scribal errors.

MS *W* includes the complete works of Ṣadr in 325 folios. The astronomy section starts at folio 247, thus extending over 78 folios only.

5) *I* refers to the India Office MS[16] which is designated by the Arabic letter *hā'* in the edition. It carries the India Office Library catalogue number Loth 532, which corresponds to a shelf number Bijapur 41: Arabic 1-532. The title of the work is given in Persian only as: *Īn Kitāb Ta'dīl al-Mīzān Dar 'Ilm-i-Kalām*, meaning "this is the book of adjusting the scale in the science of *Kalām*." This title obviously points to only one of the three topics covered in this work, namely that dealing with *kalām* (speculative theology). There are no ownership signatures on the title page.

The complete MS contains the whole work of Ṣadr in 171 folios, the last 43 of which belong to the book on astronomy. The folios are not numbered, and reference to them is made to the 43 folios of the last section by calling the first sheet folio 1, the second 2, and so on. The handwriting is clear, and the diagrams are drawn and lettered. A few corrections and comments are included in the margins of the text.

The last paragraph of the original text, in which Ṣadr specifies the date of his composition of the work, is also missing from this MS Instead, a final paragraph in Persian gives the name of the scribe, a certain Shaykh Muḥammad 'Alī, who finished writing in Bijapur in the month of Muḥarram of the year 1116 (A.H. = 1704 A.D.). Because of the late date of this MS, it was not used as the basic text of the edition.

6) *H* refers to the Hazine MS, and is designated with the Arabic letter *kha'* in the edition. It is kept in the E. Hazine collection at the Topkapi Sarayi in Istanbul, under the number 6760 E.H. 1669.[17] The title page was not supplied with the microfilm, but the MS is listed under the title *Ta'dīl al-'Ulūm*. The folios of the MS are not numbered, so, as in the previous MSS, all references to them are made to book three only, starting with folio 1 for paper 1, folio 2 for sheet 2, and so on.

The MS is executed in a beautiful hand, and is lavishly decorated. Moreover, the figures are neat and lettered, although they are not free of error. The scribe, al-Sayyid 'Uthmān b. al-Sayyid Muḥammad al-Qāriṣī, indicates in the colophon that this MS is a copy of an earlier one written by a student of Ṣadr in the year 758 (A.H. = 1357 A.D.). The scribe also states that he made every effort to rectify the present copy, and that he tried arduously to correct and polish it. He then invites his readers to compare his version with other existing copies in the "abode of the sultanate" (Istanbul). The resulting work is quite reliable, and indeed beautiful, and the only

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[16] For a catalogue reference to this MS see Loth, p. 145.

[17] For a catalogue reference to this MS see Karatay, vol. III, # 6760 E.H. 1669.

reason it was not used as a base copy is that it was completed on the date of Ramaḍān of the year 1194 A.H. (= 1780 A.D.), which is the latest date of all the 6 manuscripts used for the present edition.

THE AUTHOR AND HIS WORK

Our knowledge of the life and work of Ṣadr al-Sharī'a is scant and dispersed. It comes from various sources such as travelogues, biographies of Ḥanafī scholars and of distinguished Muslims, and catalogues of important books.[18] The entries on Ṣadr are not very long and tend to repeat information. Almost all sources praise his scholarship and knowledge, and yet they do not agree on his name.[19] The confusion over the name, however, seems to derive from the fact that Ṣadr comes from a family of famous scholars, many of whom were given the honorary title of *Ṣadr al-Sharī'a* (the supreme [one] of religion), or *Tāj al-Sharī'a* (the crown of religion). Also some of the most famous scholars of this family had the same names. Ṣadr's great-great-grandfather, for example, was also called 'Ubayd Allāh. And although he was given the title Jamāl al-Dīn, he was often referred to by his pupils as Ṣadr al-Sharī'a. Moreover, apparently the two grandfathers of Ṣadr, on both his mother's and father's side, had the name Maḥmūd, and both were scholars of great influence on the education of their grandson. Under the circumstances, some confusion regarding the name is understandable. The most elaborate biographical information on Ṣadr, however, is given in the biographies of Ḥanafī scholars written by al-Luknawī, but unfortunately most of the information is devoted to establishing Ṣadr's correct lineage, and little is offered in regard to the other aspects of his life and work.

After a careful analysis of all the available sources, the final name can be safely determined as 'Ubayd Allāh b. Mas'ūd b. Maḥmūd b. Aḥmad b. 'Ubayd Allāh b. Ibrāhīm b. Aḥmad b. 'Abd al-Malik b. 'Umar b. 'Abd al-'Azīz b. Muḥammad b. Ja'far b. Khalaf b. Hārūn b. Muḥammad b. Muḥammad b. Maḥbūb b. al-Walīd b. 'Ubādah b. al-Ṣāmit al-Anṣārī.[20]

In the above genealogical chain, two names are of special importance to our discussion, aside from Ṣadr himself: the first is the great-great-grandfa-

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[18] On the life and work of Ṣadr see Ibn Baṭūṭa, vol. III, p. 28, Luknawī, pp. 91-5, Ṭāshkoprūzāde, vol. I, pp. 60-1, vol. II, pp. 182, 191-2, Ibn Kuṭlūbughā, pp. 29, 30, 115, Dujaylī, vol. II, pp. 162-3, Zarkalī, vol. IV, p. 354, Kaḥḥāla, p. 246, Sarkīs, pp. 1199-200, Zaydān, vol. III, p. 239, Ḥājī Khalīfa, vol. II, pp. 315, 417, 601, vol. III, p. 37, vol. IV, pp. 439, 440, vol. VI, pp. 373-6, 443, 458-66, and Ṭlās, pp. 61, 69, 70, 99, 100.

[19] For the different versions of the name compare, for example, Ibn Kuṭlūbughā and Ṭāshkoprūzāde, on one hand, and Luknawī and Zarkalī on the other.

[20] See Luknawī, p. 93.

ther 'Ubayd Allāh, known as Abū Ḥanīfa al-Thānī in recognition of his rank among the scholars of his time.[21] The later biographical sources refer to him as Ṣadr al-Sharī'a al-Awwal or al-Akbar, and consistently mention his *Kitāb al-Furūq* (*The Book on Legal Differences*) which gained much fame, and became the subject of many subsequent studies and commentaries. The second famous name is Ṣadr's immediate grandfather Maḥmūd, whose treatise on applied Ḥanafī law entitled *al-Wiqāya*, was the subject of numerous commentaries and glossaries, the most famous of which is the commentary by Ṣadr al-Sharī'a al-Thānī himself.[22]

The information introduced so far establishes the fact that Ṣadr belonged to a family of traditional religious scholars. Indeed Ṣadr himself, despite his single work on astronomy, was no exception. According to his biographies, the most celebrated work Ṣadr produced is his commentary on the above mentioned *Wiqāya*, which was named after him, and on which the Ḥanafī biographies list more than thirty five commentaries and glossaries. Also of great fame was Ṣadr's summary of his own commentary, *al-Niqāya*, which gained enough prestige to have more than thirty important commentaries written about it.[23]

The above two works by Ṣadr are on the subject of positive Ḥanafī law. Ṣadr also wrote on principles of jurisprudence in his two works *Tanqīḥ al-Uṣūl*, and *al-Tawḍīḥ fī Ḥall Ghawāmiḍ al-Tanqīḥ*, which were likewise well-known, and attracted similar attention from later religious scholars and commentators.[24]

Ṣadr's other works include *al-Khamsīn fī al-Naḥw*,[25] on Arabic grammar, *al-Wishāḥ fī al-Ma'ānī wal-Bayān*,[26] on rhetoric, *al-Muqaddimāt al-Arba'a*,[27] on theology, *al-Shurūṭ*,[28] on legal stipulations and contracts, and several other unspecified works, which may include additional commentaries, and perhaps some works on *ḥadīth*.

The last work that should be mentioned in this context is, of course, the three volume encyclopaedic treatise on *The Adjustment of Sciences* (*Ta'dīl al-'Ulūm*.) The first of the three books is on logic, and as a commentary it clearly belongs to Ṣadr's intellectual output which was also written in the style of commentaries. Here, as in the two other books, Ṣadr presents what

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21 See, for example, Ḥājī Khalīfa, vol. I, p. 417.

22 See, for example, Ḥājī Khalīfa, vol. VI, p. 458-60.

23 See, for example, Ḥājī Khalīfa, vol. VI, p. 373-76, 458-66; and Luknawī, p. 94-5.

24 See, for example, Dujaylī vol. II, p. 162; Ibn Kuṭlūbughā, p. 30; Luknawī, p. 95; Ṭāshkoprūzāde, vol. II, p. 191; and Sarkīs, pp. 1199-1200.

25 See, for example, Kaḥḥāla, vol. VI, p. 246.

26 See, for example, Zarkalī, vol. IV, p. 354.

27 See Dujaylī, vol. II, p. 162.

28 See Dujaylī, vol. II, p. 162.

he estimates to be the state of the art, and then attempts to contribute to its enhancement. The second book is on theology (*kalām*), which follows quite naturally after the first. The questions discussed in these two books were not unfamiliar to theologians of the time, and it seems quite probable that a jurist would be informed in such areas of research. What is uncommon, however, is Ṣadr's competence in astronomy, which, as I will show below, is quite advanced for someone who is not a full-fledged astronomer.

This last point occasions a number of questions concerning the educational setting in the fourteenth-century Central Asian city of Bukhārā, which was perhaps similar to the state of education in many other Muslim urban centers. It also indicates the level of scholarship and originality within this setting.

Although it is beyond the scope of the present work to discuss the above issues, it might still be useful to look more closely at Ṣadr's career and environment. Aside from the distinguished lineage and the broad and accredited scholarly production that most of the available sources attribute to him, certain biographical anecdotes may be used to provide additional information about Ṣadr. The Ḥanafī biographies of al-Luknawī have entries for both the first and the second Ṣadr al-Sharī'as. While both scholars are described with the highest praise, the first of the two is distinguished as "unequaled in his time, and unique in his period, in terms of his knowledge of the [laws of the] school and [the subject of] legal differences."[29] Ṣadr al-Thānī enjoys no such unique standing.[30] And although one should not draw rigid conclusions from such scant sources, one may be justified in assuming that the second Ṣadr was only one among several other distinguished scholars.

Another useful anecdote is found in *Ṭāshkoprūzāde*: the scholar Quṭb al-Dīn al-Rāzī, teaching at Rayy, is said to have sent a student of his to attend the lessons of Ṣadr, who at the time was teaching at Herat, in order to help al-Rāzī assess the possibility of his prevailing against Ṣadr in a debate. The pupil then found Ṣadr teaching Ibn Sīnā's *Kitāb al-Ishārāt*, without reference to a written copy of the text or any of its major commentaries. He then advised his teacher to forgo the idea of the debate.[31] The interesting points in this anecdote are two: the first is that Ṣadr taught in Herat, and not only in Bukhārā, and that he taught there, with at least some competence, the works of Ibn Sīnā. The second point is that there were other famous scholars teaching in the same region, who were comparable to Ṣadr in their knowledge, and had interest in engaging in some sort of competitive debate. The fact that Ṣadr was active in Bukhārā is also evident from other sources,

[29] See Luknawī, p. 92.
[30] See Luknawī, p. 94-5.
[31] See Ṭāshkoprūzāde, vol. II, p. 191-2.

such as Ibn Baṭūṭa, who mentions actually meeting Ṣadr after the latter's return from Herat.[32]

Although Bukhārā was "the most prosperous of the towns in Transoxiana,"[33] the Mongol invasion devastated the city, and in the early part of the eighth (fourteenth) century when Ibn Baṭūṭa visited the place "...the mosques, colleges and markets were still for the most part in [a] state of ruin."[34] Bukhārā was, at this time, part of the domain of the Chaghatay Khānate of Transoxiana,[35] which, after a succession of short-lived dynasties, took over the control of what used to be the site of the prosperous Sāmānid rule.[36] The Chaghatays, on the other hand, were busy competing with the more successful IlKhāns, and with the Golden Horde state. Moreover, even by the time they were dislodged by the Tīmūrids, they had not yet consolidated their internal power.[37] In short, the fourteenth century was a period of political turbulence and instability, which may not have contributed to the enhancement of educational and cultural life.

Religiously, a mixture of interests seem to have dominated the scene, although there is evidence that the Ḥanafī legal school, and a brand of the Māturīdī theology were prevalent in Transoxiana. Moreover, Naqshbandī sufism flourished in Bukhārā as a "traditionally Ḥanafite, strictly Sunnite, and urban based order."[38]

What we have, therefore, is a phenomenon of reasonable intellectual productivity, of which Ṣadr is a representative rather than an exception. This productivity, however, takes place while the surrounding political atmosphere is not particularly conducive to it. Thus, an explanation of such activity ought to be sought beyond the boundaries of political culture, perhaps by looking at the more durable social institutions and intellectual traditions that manifested a level of resilience and flexibility in adapting to political changes, but which, at the same time, retained their own character and momentum independently of these changes.

The Adjustment of the Configuration of the Celestial Spheres can now be used as a case in point. The work was finished in the year 747 A.H. (1347 A.D.), the year of the death of its author. The motive for writing it, as expressed by Ṣadr in the beginning of the book, is to resolve the problems of the longitudinal motion of the moon and the other planets, as well as the latitude motion. Ṣadr adds that he is addressing these questions since "none of

[32] See Ibn Baṭūṭa, vol. III, p. 28.
[33] See Minorsky, p. 112, and Morgan, pp. 20-2.
[34] See Strange, p. 286, and Hodgson, vol. II, p. 410.
[35] See Morgan, pp. 83-7, and Hodgson, vol. II, p. 410.
[36] See Morgan, pp. 22, and Hodgson, vol. II, p. 410.
[37] See Hodgson, vol. II, p. 416.
[38] See Madelung, p. 51.

the ancients had addressed them, and since none of the arrows of the latter (scholars) did hit the mark (regarding them)." The resulting work is indeed a revision of the astronomical tradition from within its own existing framework. In this Ṣadr was obviously driven by the momentum of the revisionist tradition mentioned earlier, which must have established certain standards for education and learning.

Unlike earlier astronomers, such as 'Urḍī, for example,[39] Ṣadr does not feel a need to expose the problems of the Ptolemaic models, nor does he concern himself with discussing these models directly. Rather, Ṣadr assumes the level of research achieved in the Maragha school as common knowledge among the practitioners of the science of astronomy, and critiques and attempts to modify it. This suggests that the field of astronomical research was well delineated within the framework of the above problems, and by extension, that a community of researchers was actively engaged in these problems.

Two sources stand out for their marked influence on Ṣadr's work on astronomy, as well as his astronomical education: these are the *Tadhkira* of Naṣīr al-Dīn al-Ṭūsī, and the *Tuḥfa* of Quṭb al-Dīn al-Shīrāzī. Ṣadr's reference to these two works is explicit, and he quotes both extensively. It would seem that by Ṣadr's time, these two works served as textbooks. And although it is almost certain that there were other influences on Ṣadr, the above works have a proportionally more important influence on him than any other. For this reason, the following commentary tries to trace and identify the relation of the present work to its two major sources.

THE CONTRIBUTIONS OF ṢADR AL-SHARĪ'A TO ASTRONOMY

A complete assessment of Ṣadr's contributions will be found in the following commentary. In this section a short summary of those contributions will be presented. It is assumed that the reader has some working knowledge of basic astronomical terms, and that further clarification may be obtained by reading the present section in conjunction with the corresponding commentaries that follow.

As mentioned earlier, Ṣadr assumes the reader's familiarity with the astronomical tradition aimed at reforming the Ptolemaic astronomy. Moreover, his exposition of the Ptolemaic models is cursory and at best descriptive. The main value of Ṣadr's expositions is that they present the different modified models proposed by Ṭūsī and Shīrāzī. And although Ṣadr does not produce an exhaustive account of all such propositions, he does include, with very few exceptions, the major ones.

[39] See Saliba, 1990, pp. 45-7.

Had the above task been the only one which Ṣadr undertook, his work, at its best, would have been another summary of earlier contributions. Ṣadr's research project, however, is more ambitious. He proposes to review critically the models of his two predecessors, and in the course of this revision produce his own models. His presentation of the models of Ṭūsī and Shīrāzī is thus for the definite aim of assessing them, and, wherever needed, replacing them. Indeed, the results of this undertaking are far from trivial, and Ṣadr was successful in his attempts to tackle such issues.

To take a few examples of Ṣadr's contributions, I draw attention to his model for the longitudinal motion of the moon.[40] Two problems are raised in relation to the Ptolemaic model of the moon: the first is that the center of the deferent is itself moving, and the motion of the center of the epicycle on this deferent is not uniform around the former center, but rather around the center of the world. The second problem is the so-called problem of the prosneusis point, which is the point diametrically opposite to the center of the deferent on the other side of the center of the world. The anomalistic motion on the epicycle is measured away from the mean epicyclic apogee aligned with this movable prosneusis point, rather than being measured from the true apogee aligned with the center of the world.

Ṣadr's solution for the above problems is preceded by presentations of the models of Ṭūsī and Shīrāzī. He then notes that the latter model, which is itself based on 'Urḍī's solution, does not solve the problem of the prosneusis point, and proceeds to modify it by adding still a third small epicycle. As noted in the following commentary, the resulting configuration is quite successful in resolving the theoretical problems of the lunar model, and in predicting the lunar positions in accordance with the Ptolemaic model.

The second problem which Ṣadr claims to solve is that of the model for the longitudinal motion of the superior planets.[41] The main problem of this model is the so-called problem of the equant point: the center of the epicycle rotates on a circle, but its uniform motion would not be measured around the center of this carrying circle, but rather around the equant center. Moreover, the anomalistic motion would be measured from the mean apogee aligned with the equant point rather than being measured from the true apogee aligned with the center of the world.

Ṣadr presents a model in which the above difficulty is resolved, although he does not acknowledge that this is not his own contribution; it is, in fact

[40] For the objections raised against the Ptolemaic model see the commentary on chapter 5, paragraph [16]. For a discussion of Ṣadr's model see the same chapter, paragraph [32].

[41] On the objections to the Ptolemaic model of the upper planets see the commentary on chapter 6, paragraphs [11]-[12]. For Ṣadr's solution see the same chapter, paragraphs [11]-[13].

the same solution proposed by Shīrāzī, who in turn based it on the earlier work of 'Urḍī.

The third problematic model is that of Mercury.[42] The problem of the equant point is further complicated in this case because the center of the deferent itself rotates around the center of another sphere called the director. Ṣadr correctly points out that Ṭūṣī did not solve the above problems, but he does not bother to present Shīrāzī's complicated model, and instead, he moves on to present his own. The solution proposed by Ṣadr utilizes two mechanisms which are not completely new. His ingenuity, however, lies in bringing the two together. The first of these is the tool already used in the model of the moon. It involves using the lemma developed by 'Urḍī, together with an additional epicycle. This step would make all circular motions uniform around their own centers. The second tool employed is a spherical Ṭūṣī couple, which aligns the epicyclic apogee with the equant center rather than with the center of the director. Again, the point to note here is that this new model was only possible through close and thorough analysis of the earlier works. And although no new elements were introduced, great ingenuity was needed to produce a new composition of the old elements.

Finally, the last set of problematic models which Ṣadr attempted to rectify are those of the motion in latitude.[43] Here too, Ṣadr's own hybrid models evolve through a close analysis of those of his predecessors. In the case of the upper planets, he uses two sets of spherical Ṭūṣī couples, while in the case of the lower planets one spherical couple is used in conjunction with the inclining sphere proposed by Shīrāzī.

EDITORIAL NOTE

The language of *Ta'dīl Hay'at al-Aflāk* is convoluted. Furthermore, it suffers from the lack of fixed rules concerning gender agreement. The verbs and their subjects, and even the nouns and their adjectives, do not always agree in gender. Since in most cases the practice of Ṣadr can be considered acceptable, although not common, I changed the gender only when it appears to be clearly an error, but I noted the original reading in the critical apparatus.

The other problem arises in separating the text from the comments. On some occasions, it is hard to distinguish between the text and the comments,

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[42] For the objections in the case of Mercury see the commentary on chapter 7, paragraph [14]. For Ṣadr's solution see paragraphs [15]-[23] of the same chapter.

[43] For Ṣadr's discussion of the latitude theory for the lower planets see the commentary on chapter 8, paragraphs [29]-[33]. For the upper planets see paragraphs [45]-[50] of the same chapter.

and the situation is not uniform in all MSS The main criterion for establishing the correct variant was to look at the contents of the text in question, and see whether it included new substantive material, or whether it is a mere explanation of an earlier sentence. Moreover, the succession text-comment-text, in this order, is quite often a clue, since a missing link has to be provided. In general, however, it was easy to determine and there were very few cases where I had difficulty in determining the right succession without the aid of external evidence.

The text also uses a number of symbols to abbreviate frequently used Arabic words, such as *mṭ* for *maṭlūb*, *al-ẓ* for *al-ẓāhir*, etc. These words are written in full form in the edition, and were only noted in the critical apparatus at their first occurrence.

Another frequently recurring problem concerns the medieval loose convention for the writing of the *hamza* "chairs." Such conventions were never codified and the same word containing a *hamza* could be written in a variety of ways by various scribes. Even when the same word is repeated by the same scribe, the chair for the *hamza* is at times changed, without regard for principles of consistency. In such instances, I follow the modern conventions of spelling without referring to the original form of the word in the MS, in order to reduce the size of the critical apparatus.

Similarly, Qur'ānic spelling conventions are reproduced according to modern usage. Moreover, dagger *alifs* in words like *thalāth* are also changed to long *alifs*, without indication in the critical apparatus.

The notes written on the margins by hands different from the one copying the main text were mentioned and incorporated only if they were corrections to the text. Otherwise, they were consulted as commentaries on the text and were not included in the text nor in the critical apparatus.

MSS *W* and *I* included numerous errors which are clearly scribal, and which otherwise cannot be considered variant readings; Moreover, MS *H* is copied from MS *B*. Therefore, these three MSS were used to clarify and facilitate the reading of the other three, namely MSS *A*, *B*, and *G*, and, with few exceptions, only the variants of the latter three were noted in the critical apparatus.

In the Arabic text I have used square brackets to mark the MS sigla and folio numbers of all six MSS. I have also used square brackets to indicate the sequential paragraph numbers which are obviously not part of the original text. Other words I added to the text for reasons of clarity, are put in parentheses.

Finally, all letters left undotted in the original were spelled according to modern usage. I have also added punctuation marks, which are lacking in the original, as is the case in most medieval MSS, in order to delineate what I believed was intended by the text.

As for the accompanying English translation and commentary, the paragraphs of each chapter were numbered following the numbering of the Arabic text. These numbers appear inside square brackets. Square brackets were also used for the MS page number of the base MS *A* which were added to the English translation. The reference to other MSS can be obtained Only from the Arabic edition. Words in parentheses have been added to the translation in order to conform to English idiom as much as possible, and to clarify the meaning. In the translation, figure numbers have been inserted in parenthesis when there were such corresponding figures in the Arabic text. Additional figures that did not appear in the original have been inserted in the commentary.

References to secondary literature are cited in an abbreviated form. Most abbreviations have the "author, date" format. In few cases, however, different abbreviations are used, and these are provided in parentheses before the full citations given in the bibliography.

TEXT AND TRANSLATION

[١] [أ ١ظ، ب ١٨٤ظ، ج ٠ظ، ف ٢٤٧ظ، هـ ١و، خ ١ظ] بسم الله الرحمن الرحيم. توكلي عليه[١].

[٢] الحمد لله الذي زين السماء بالبروج بعدما أحكم بناءها، فقال: «وزيّناها وما لهامن فروج»،[٢] والصلوة على رسوله الذي جعله «سراجا منيرا»،[٣] ومن نوره مستنيرا،[٤] وجعل آله[٥] وأصحابه نجوما، ولشياطين الإنس والجن رجوما.

[٣] وبعد، فأن العبد المتوسل إلى الله تعالى بأقوى الذريعة، عبيد الله بن مسعود بن تاج الشريعة، آتاه الله سعادة الدارين يقول:

[٤] هذا تعديل هيئة الأفلاك، وهو القسم الثالث[٦] من كتاب تعديل العلوم، حررتها تبصرة وتذكرة لذوي الإدراك، موردا في هذا الكتاب ما تحير فيه عقول أولي الألباب، كحل إشكال القمر وسائر الكواكب، وإثبات الأفلاك بعروضها،[٧] فأنه لم يتعرض لها أحد من المتقدمين، ولم تتوجه لصوب الصواب سهام المتأخرين. فكتبت ما هداني الله له

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[١] توكلي عليه: رب يسر ولا تعسر [ج]

[٢] و زيّناها ... فروج: العبارة، سورة ق، ٦

[٣] سراجا منيرا: العبارة، سورة الأحزاب، ٤٦

[٤] ومن نوره مستنيرا :العبارة، غير واضحة [أ]، سقطت [ج]

[٥] وجعل آله: العبارة، غير واضحة [أ]

[٦] الثالث: الكلمة، على الهامش [ج]

[٧] بعروضها: لعروضها [ج]

[CHAPTER 1]

[1] [f. 1v] In the Name of God the Merciful, the Compassionate. My trust is in Him.

[2] Praise be to God who embellished the sky with constellations after securing its construction thus saying: "and We adorned it, and there are no flaws in it", and may prayers be on His messenger whom He made "as a lamp spreading light", and who derives his enlightenment from Him, and whose family and companions He made as stars (for the believers), and missiles for the evil humans and jinns.

[3] Now, the worshiper pleading to God, the Exalted, with the most urgent of pretexts, 'Ubayd Allāh ibn Mas'ūd ibn Tāj al-Sharī'a, may God grant him happiness in the two abodes, says:

[4] This is (a work on) the Adjustment of the Configuration of the Celestial Spheres, and it is the third part of the Book of the Adjustment of the Sciences, which I composed for the purpose of enlightening and reminding those who are endowed with reason. In this book I include (questions) that have confused the minds of men of understanding, such as the resolution of the difficulties of the moon and the rest of the planets, and the determination of the latitude (motions) of the celestial spheres, since none of the ancients had addressed them, and since none of the arrows of the latter (scholars) did hit the mark (regarding them). I thus wrote down whatever God has inspired me with,

وغير ذلك مما إذا طالعته وطالعت الكتب المصنفة في هذا الفن تعرف مقداره، سائلا من الله تعالى إلهام الصواب وفتح مغلقات الأبواب.

[٥] فأقول: علم الهيئة علم الأجرام العلوية والأربعة السفلية من حيث هيآتها وكمياتها وأوضاعها وحركاتها اللازمة لها. [أ ٢و، ب ١٨٥و، ج ١و، ف ٢٤٨و، هـ ١ظ، خ ٢ظ] وموضوعه هي بشرط[1] تلك الهيئات،[2] [ف ٢٤٨ظ] أو هي بلا شرط وهو الأصح. [أ ٢ظ، ج ١ظ] ومبادؤه هندسيات وطبيعيات، ومسائله تذكر في تعديلين:

[٦] أما الهندسيات ما يشار اليه حسا، وليس بجوهر: [ب ١٨٥ظ] إن لم يكن له جزء فنقطة، وإن كان فمقدار متصل وبعد ممتد. والامتداد الواحد طول، والثاني القاطع له عرض، والثالث القاطع لهما عمق. فالممتد الأول خط. وإذا قطعت الامتدادات الثانية الأول على [خ ٣و] كل من أجزائه فمجموع الممتد سطح. وإذا قطعت الثالثة السطح على كل من أجزائه فمجموعه جسم تعليمي. [ف ٢٤٩و]

[٧] وقد قيل الخط طول فقط، والسطح الامتدادان، والجسم التعليمي ثلاث. فيلزم أن يكون الخطان المتقاطعان سطحا، والثلاثة المتقاطعة جسما تعليميا.[3]

[٨] والجسم ينتهي بلا واسطة بالسطح، وهو بالخط أو بالنقطة،

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[1] بشرط: شرط [أ]

[2] الهيئات: الحيثيات [ج، خ]

[3] تعليميا: +«ش»، ثم شطبت [أ]

and more, such that once you read it (i.e. the book) together with the (other) books composed on this subject, you will know its worth. I plead to God, the Exalted, for inspiration to the truth and for the unlocking of closed doors.

[5] I say: the science of astronomy is the science (dealing with) the upper (celestial) bodies together with the four lower ones with respect to their configurations, quantities, positions, and motions that are intrinsic to them. [f. 2r] Its subject is those (bodies) under the constraints of such configurations or, more correctly, without these constraints. [f. 2v] Its principles are geometrical and physical, while its problems will (soon) be mentioned in two tracts:

[6] As for the geometrical (principles), they (deal with) that which can be indicated through the senses, and is not itself an essence: if it has no (divisible) part then it is a point, otherwise it is a continuous quantity and an extended dimension. The singular dimension is length, the second intersecting it, is width, while the third, intersecting both, is depth. Thus the first dimension is a line. If the other dimensions intersect the first one at each of its parts then the generated dimension is a plane. And if the third intersect the plane at each of its parts then the result is a mathematical solid.

[7] Some have maintained that a line is simply a length, while the plane is two dimensions, and the mathematical solid is three. This entails (the assertion) that two intersecting lines form a plane, and that three intersecting (lines) form a mathematical solid.

[8] A solid, with the absence of an intermediary, ends in a plane, while it (i.e. the plane ends) in a line or in a point,

كالمخروط، والخط بالنقطة إن كان ذا نهاية معينة. [أ ٣و] وإن [هـ ٢و] أطلق الانتهاء فالجسم ينتهي بما سواه.

[٩] والخط المستقيم ما تتحاذى جميع نقطه. [ج ٢و] وفي التحفة «ما يستر وسطه طرفه إذا وقع في امتداد شعاع البصر». أقول:[١] إن عني أنه يستره حتى[٢] لا يبصر فممنوع، لأن محل الروح الباصرة أعظم من النقطة. [ب ١٨٦و، ف ٢٤٩ظ] وإن عنى[٣] معنى آخر فغير معلوم.

[١٠] والسطح المستوي ما يمكن أن يفرض خطوط مستقيمة في طوله وعرضه.

[١١] والزاوية المسطحة سطح بين خطين ملتقيين عند نقطة بحيث لم يتحدا، بلا اعتبار الخط الثالث وكمية الخطين. بل يكفي ما يطلق عليه الخط. [أ ٣ظ، ج ٢ظ، ف ٢٥٠و] وفي التحفة «هيئة تحدث عند نقطة من السطح من حيث هو ذو حدين متصلين بتلك النقطة.» أقول: الظاهر أنها عند المهندسين[٤] سطح يعرض لمحدبه وضع، وهو هيئة الانحداب. فلهذا يقسم، فيقال هذه نصف تلك، ولا يقال هذه الهيئة نصف تلك، على أن الهيئة الحاصلة من السطح لا تنقسم.

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[١] أقول...: الفقرات حتى نهاية الفصل الأول، سقطت [خ]

[٢] حتى: + حيث، تحت السطر [أ]

[٣] عنى: معنى [ب]، ثم صححت في الهامش

[٤] المهندسين: الهندسيين [أ،ج]

as in the cone, while the line (ends) in a point, provided it has a specific limit. [f. 3r] If, however, limit is used in a general sense, then a solid ends in (that which is) other than itself.

[9] A straight line is (a line) whose points are in the same direction. In the *Tuḥfa* it is (defined as) "that whose middle (part) covers its end if it falls along the ray of sight". But I say: if he (i.e. Shīrāzī) meant that (the middle) covers (the end), such that it is not seen, then it (i.e. the above definition) is not permitted, since the place of the ocular soul is greater than a point. If, however, he meant something else, that remains unknown (to us).

[10] A plane surface is that in which straight lines could be assumed in length and in width.

[11] A plane angle is a surface between two lines intersecting at a point such that (the lines) do not coincide, irrespective of a third line or of the size of these two lines. Indeed it is sufficient to have (only) that which is defined as line. [f. 3v] In the *Tuḥfa* (an angle) is (defined as) "a configuration generated at a point of a surface so that the two edges (of that surface) are connected at that point." But I say: according to the geometers it is apparently a surface the curvature of which is in a specific position, which is itself the configuration of the curvature. For that reason it (i.e. the angle) is divisible, and one may say this (angle) is half of that, but one could not say this configuration is half of that, since the configuration generated by the surface is not divisible.

[١٢] [ب ١٨٦ظ، هـ ٢ظ] والمجسمة[١] جسم، محدود بالزوايا المسطحة، أو سطح ينتهي عند نقطة، كما في رأس[٢] المخروط، بلا اعتبار الحد الآخر.

[١٣] الدائرة سطح مستو يحيط به خط مستدير يسمى محيطا، في داخله نقطة تسمى مركزا، كل الخطوط المستقيمة منها إليه متساوية وهي أنصاف[٣] أقطارها، والخارج في الجهتين قطرها. [أ ٤و] وخط مستقيم يقسمها قسمين[٤] وترها، وما انفصل به من المحيط قوس. ونصف الوتر جيب لنصف القوس. والعمود الخارج من منتصف القوس الى منتصف الوتر سهم لذلك النصف.

[١٤] الكرة جسم مستدير يحيط به[٥] سطح مستدير، كل الخطوط المستقيمة من نقطة في داخله اليه متساوية، وإذا دارت حدث من دوران كل نقطة عليها دائرة.

[١٥] الفلك جسم كري علوي لا يحجب ما وراءه، متوازي السطحين إن كان شاملا للأرض. [ب ١٨٧و، ج ٣و، ف ٢٥٠ظ]

[١٦] /وأما الطبيعيات، فالجسم إن تركب من أجسام مختلفة

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[١] والمجسمة: +«أي الزاوية تنقسم»، فوق السطر [ب]، الجسمية [هـ]

[٢] رأس: «نقطة»، ثم شطبت وصححت في الهامش [ب]

[٣] أنصاف: اتصاف [ج]

[٤] قسمين: بقسمين [ج]

[٥] به: الكلمة، سقطت[أ]

[12] A solid (angle) is a solid defined by plane angles, or a solid which ends in a point, as in the case of the tip of a cone, irrespective of the other boundary.

[13] A circle is a plane surface bound by a curved line called the circumference, inside which there is a point called the center, such that all straight lines (issuing) from it to the circumference are equal, and these are its radii, whereas a line issuing (from the center) in two directions is its diameter. [f. 4r] A straight line that cuts it (i.e. the circle) into two parts is its chord, and the part of the circumference that is thus separated is an arc. Half the chord is the sine of half the arc. A perpendicular issued from the midpoint of the arc to the midpoint of the (corresponding) chord is the versed sine of that half.

[14] A sphere is a round solid bounded by a circular surface such that all the straight lines issued from a point inside it to the (circular surface) are equal. If it (i.e. the sphere) rotates, a circle is generated by the rotation of each point on it.

[15] An orb is a celestial spherical solid which does not obscure whatever lies behind it, its two surfaces will be parallel when it includes the earth.

[16] As for the physical (principles), if a body is composed of (other) bodies having different

الطبيعة فمركب، كالمعادن والنبات[1] والحيوان والآثار العلوية والسفلية. وإلا فبسيط، وهو العناصر والأفلاك والكواكب. وقد مر في الكلام ما ينفي بساطتها، كمحو القمر [أ ٤ظ] ونحوه. وقد مر أيضا أنه لو خلّي وطبعه يكون كريا، مع ما يرد عليه.

[١٧] ثم الأفلاك متحركة على الاستدارة ولكل حركة مبدأ. فلو كان متعلقا بالمتحرك [ف ٢٥١و] بلا واسطة أو بها فهو متحرك بنفسه أو بغيره. ولم نقل كما قال في التذكرة إن «المتحرك إن لم يفارقه مبدؤه»، إلى آخره، [ج ٣ظ، هـ ٣و] لأن المبدأ قد لا يكون ذا وضع، أي مشارا إليه.

[١٨] فالمتحرك بنفسه إن كان حركته على نهج[2] واحد سمي المبدأ طبعا. وقسمت على طبيعية[3] عنصرية مستقيمة، وإرادية فلكية دورية. لكن الحصر ممنوع. وإن لم يكن سمي المبدأ نفسا نباتية أو حيوانية.

[١٩] و المتحرك بغيره إن كان جزءا من المحرك،[4] أو متمكنا فيه فحركته عرضية؛ وإلا فقسرية. [ب ١٨٧ظ] والحق أن الدلائل على كون حركة الأفلاك إرادية في غاية الضعف على ما مر في الكلام. [أ ٥و]

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[1] /وأما...النبات: العبارة، شرح [ف]

[2] نهج: الكلمة، غير واضحة [أ]

[3] طبيعية: طبيعة [ج]

[4] المحرك: المتحرك [ج]

natures, then it is a compound (body), such as minerals, plants, animals, and the upper and lower meteorological phenomena. Otherwise it is simple, and that (comprises) the elements, the orbs, and the planets. But in the section on *kalām* the negation of their (i.e. the planets') simplicity is mentioned, as in (the case of) the spots (on the face) of the moon [f. 4v] and the like. It is also mentioned therein, together with the objections that could be raised, that if it (i.e. the simple body) were left to its nature it would be spherical.

[17] Moreover, the motion of orbs is circular, and every motion has a principle. If it (i.e. the principle of motion) is contiguous to the mobile, with or without an intermediary, then it (i.e. the mobile) is either moved by something other than itself, or self-moved. We do not maintain that which is asserted in the *Tadhkira*, namely that "if the principle of motion of the mobile is not separated from it," et cetera, because the principle of motion may not be in such a situation that can be (specifically) designated.

[18] If the motion of the self-moved is in a uniform manner, then the principle of motion is called a nature (of the mobile). (This motion) is then divided into linear and natural for the elements, or circular and voluntary for the celestial bodies. This restriction (of the various motions to specific elements), however, is not permissible. If on the other hand (the motion) is not (uniform), then the principle of motion is called a plant or an animal soul.

[19] If the (mobile) which is moved by something other than itself is a part of the principle of motion or grounded in it, then its motion is accidental; otherwise it is by compulsion. Indeed, the evidence for the motion of the orbs as being voluntary is extremely weak, as has already been mentioned in the section on *Kalām*. [f. 5r]

ومع ذلك لا يضر لصاحب هذا الفن، إذ يكفيه أن حركة الفلك إما بلا تبعية فلك آخر أو بها، كحركة المحوي بالحاوي. فقيل إنما تجب إذا كان المحوي خارج مركز [و][١] لم يمر محور الحاوي على مركز المحوي، [ف ٢٥١ظ] إذ لو لم يتحرك، يلزم تداخل الأجسام، أو خروج الحاوي عن حيزه، لأن المتمم الحاوي غير متوازي السطحين. [ج ٤و] أو كان قطب المحوي طالبا لجزء معين من الحاوي، فحينئذ لو لم[٢] يتحرك به لزال قطب المحوي عن مكانه الذي يطلبه. لكن بساطة الحاوي تنفي كون جزء معين منه[٣] بحيث يطلبه القطب بالطبع. ولو سلم هذا، فما طريق الحركة[٤] اليومية لما سوى فلك البروج؟

[٢٠] وقد زيف صاحب التحفة هذا وقال: لو كان نفس الحاوي في القوة بحيث يحرك المحوي، تحرك، وإلا لا. سواء كان خارج مركز، يمر محور الحاوي على مركز المحوي، [أ ٥ظ] أو لا، أو لا[٥] يكون خارج مركز، منطبقا قطبا المحوي على قطبي الحاوي أو غير منطبق، فإن الاعتبار لقوة نفس الحاوي، لا لما ذكر.[٦] فإذا كانت قوة النفس بتلك

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[١] [و]: الكلمة، سقطت [أ، ب، ج، ف، هـ، خ] وأضيفت للمعنى

[٢] لم: +يكن، ثم شطبت [ج]

[٣] معين منه: منه معين [ج]

[٤] الحركة: حركة [ج]

[٥] أو لا: العبارة، سقطت [ج]

[٦] ذكر: +«من حديث التشبث»، تحت السطر [أ]

Nevertheless this does not militate against anyone holding such a view, since it suffices to such a person that the motion of the orb be either without dependence on another orb or with it, as in (the case of) the movement of the encompassed orb by the encompassing orb. It was, however, maintained that it (i.e. the movement of the encompassed orb) becomes necessary (under two conditions): if the encompassing orb is eccentric, such that the axis of the encompassing orb does not pass through the center of the encompassed one, such that if it (i.e. the encompassed one) does not move, then the necessary result will either be the interference of solid bodies, or that the encompassing sphere will move out of its confines, because the two surfaces of the complementary solid of the encompassing orb are not parallel. (Second) if the pole of the encompassed orb seeks a specific part of the encompassing one, in that case if (the encompassed orb) is not moved, then the pole of the encompassed orb would be separated from the point which it seeks. Yet the simple (nature) of the encompassing orb does not permit that a specific part of it be naturally sought by the pole. If that were granted (i.e. that the pole would naturally seek a point), then what would explain the daily motion of all that is below the zodiacal orb?

[20] This (preceding argument) was repudiated by the author of the *Tuḥfa* who said: if the soul of the encompassing orb is strong enough to move the encompassed orb, then it will move, otherwise it will not. This is equally true whether there is an eccentric orb, in which the axis of the encompassing orb passes through the center of the encompassed one or not, [f. 5v] or whether there is no eccentric orb in which the two poles of the encompassed orb do or do not coincide with the two poles of the encompassing one, since (only) the strength of the soul of the encompassing orb is relevant, and not the (above-) mentioned (factors). Thus if the strength of the soul is in such a

الهيئة،[١] تحرك بلا شرط آلة جسمانية.

[٢١] أقول: للمحوي نفس، فأن له حركة خاصة. فنفس الحاوي [ب ١٨٨و] إن تعلق به [هـ ٣ظ] أيضا، فله نفسان يكون[٢] بهما حيا، ويوجبان حركتين مختلفتين له. و هذا بعيد عن الحق ولم يذهب اليه أحد. وإن لم يتعلق بالمحوي فالحاوي يحركه قسرا، [ف ٢٥٢و] فلا بد من سبب جسماني تجب به الحركة.

[٢٢] وقد سنح لي طريق[٣] حسن، وهو أن تكون الممثلات في ثخن الفلك الأعظم، بمنزلة الخارج المركز في الممثل، فيكون مركزها[٤] خارجا عن مركز العالم خروجا قليلا لا يحس به اختلاف الحركات. [ج ٤ظ] فالمتمم الأعلى يحيط بالكل والأسفل يماس كرة النار. ولا يجب انفصال ممثل[٥] كل كوكب عن ممثل الآخر، إذ ليس لكل واحد حركة على حدة. فيكفي ممثل واحد في ثخنه خارجات المراكز الست، أي ما عدا القمر، [أ ٦و، ف ٢٥٢ظ] فأن حركة جوزهره توجب انفصال ممثله عما فوقه. ثم مع ذلك تجب له الحركة اليومية، لأن المتمم الأعلى للفلك[٦] الأعظم

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[١] الهيئة: الحيثية [ب، ج]

[٢] يكون: الكلمة، تكررت [ب]، ثم شطبت الثانية

[٣] طريق: +"وجه"، قبلها ثم شطبت [أ]

[٤] مركزها: الكلمة، سقطت [ج]

[٥] مثل: الكلمة، سقطت [ج]

[٦] للفلك: +"متمم"، قبلها [أ]

manner, then it (i.e. the encompassed orb) will move without the need for a physical instrument.

[21] But I say: (if) the encompassed orb has a soul, then it would have a special motion. Now, if the soul of the encompassing orb were contiguous with it too, then it (i.e. the encompassed orb) would have two souls through which it becomes alive, and these would necessitate two different motions for it. This, however, is far from being true, and no one maintains it. If, on the other hand, it (i.e. the soul of the encompassing orb) were not contiguous with it, then the encompassing orb would move it by compulsion, in which case there should be a physical cause that brings about the movement.

[22] A proper method (for solving the above problem) has occurred to me, namely, let the parecliptic (orbs) be embedded within the thickness of the great orb, as is the eccentric (orb) within the parecliptic (orb itself), then their center will be slightly offset from the center of the world, (but) in a way that renders the difference in motion non-detectable. The upper complementary solid thus surrounds all other (orbs), while the lower one is contiguous to the sphere of fire. It is then not necessary to separate the parecliptic solids of the different planets, since none of those have their separate motion. Thus it is sufficient to have one parecliptic within which are embedded the six eccentric orbs; that is with the exception of the moon, [f. 6r] since the motion of its nodes entails the separation of its parecliptic from that which is above it. Yet in spite of this, its (i.e. the moon's) daily motion is necessary, because the upper complementary solid of the great orb

يوجب حركة جميع ما تحته. [ب ١٨٨ظ] فعلى هذا يكفي سبعة أفلاك، لأن المتمم ليس فلكا،[1] وكذا المتممان؛ بل هما مع ما[2] بينهما فلك واحد مشتمل على سبعة.

[٢٣] ولا يجب للحركة الثانية فلك على حدة، فالثوابت التي يكسفها زحل تكون على متممه الأعلى. [ج ٥و] وغيرها يجوز أن يكون تحت زحل. فممثله[3] يتحرك حركة ثانية. و الله أعلم بالصواب[4].

[1] فلكا: بفلك [ج]

[2] ما: +«جميع»، بعدها [ج]

[3] فممثله: فممثل زحل [ب]

[4] بالصواب: +بالحق، قبلها [ب]

necessitates the movement of everything that falls below it. Therefore, seven orbs are sufficient, since the complementary solid is not an orb, nor are two complementary solids (orbs); rather they, together with what falls between them, are one orb enclosing seven (orbs).

[23] Moreover, the second motion does not require a separate orb, since the fixed stars that are eclipsed by Saturn are located on its upper complementary solid, while others could possibly be located below Saturn. Therefore, its parecliptic has a second motion. And God knows the truth best.

[١] تعديل مباحث الأفلاك

[٢] فصل: [هـ ٤و] في كرية العالم وترتيبيه.

[٣] استدلوا على كرية الفلك بأن الكواكب[١] تدور بالحركة اليومية حول قطب العالم على دوائر متوازية. كل ما هو أقرب منه فمداره أصغر. ثم منها ما لا يخفى، ثم ما يخفى قليلا، ثم ما يتساوى ظهوره وخفاؤه كمعدل النهار، ثم ما يظهر قليلا. والمداران على جانبي المعدل ببعد واحد، ظهور أحدهما كخفاء الآخر. [أ ٦ظ، ب ١٨٩و، ج ٥ظ، ف ٢٥٣و، خ ٣ظ] وبارتفاع الكواكب[٢] قليلا قليلا، وانحطاطها[٣] كذا، وتساوي أجرامها فى جميع الأبعاد إلا في الأفق، فأنها أعظم بسبب البخارات. [ف ٢٥٣ظ] وبظهور نصف الفلك أو قريب منه. [أ ٧و]

[٤] وعلى كرية الأرض بأن طلوع الكواكب وغروبها في البلد الشرقي قبلهما[٤] في الغربي. الدال على هذا اختلاف[٥] زمان وسط الخسوف، [هـ ٤ظ] وبأن ارتفاع الكوكب الشمالي وانحطاط الجنوبي يزداد للذاهب الى الشمال، والجنوبي[٦] للذاهب الى الجنوب. [ج ٦و،خ

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[١] الكواكب تدور: الكوكب يدور [ج]

[٢] الكواكب: الكوكب [ج]

[٣] انحطاطها: انحطاطه [أ، ج، ب]

[٤] قبلهما: قبلها [أ]

[٥] اختلاف: لاختلاف [ج]

[٦] الجنوبي: للجنوبي [ب]

[1] [Chapter 2] Adjustments Regarding the Discussions of the Celestial Spheres.

[2] Chapter: On the Sphericity and the Order of the Universe.

[3] The sphericity of the celestial orb is inferred from the following: the stars, in their daily motions, rotate around the pole of the world along parallel circles. Those (stars) which are closer to it (i.e. to the pole), have smaller day circles. Among these (circles) are those which do not disappear, those which disappear briefly, those whose (periods) of appearance and invisibility are equal, such as the (circle of the) equator, and those which appear briefly. If two day circles are equidistant from the equator, then the apparent (portion) of one of them is equal to the invisible (portion) of the other. [f. 6v] (The sphericity is also inferred) from the gradual rising and setting of stars, and from (the fact) that their bodies are of equal (sizes) at all positions, except when they are on the horizon, where they (appear) bigger due to vapors. (The sphericity is also inferred) from (the constant) appearance of one half the celestial orb, or something close to that.

[4] [f. 7r] The sphericity of the earth (is also inferred) from the rising and setting of stars, (as they appear) in eastern localities, earlier than in western localities. The proof for the above is in the difference in the times of the midpoint of the (same) lunar eclipse. (The sphericity is also inferred) from (the fact) that the altitude of a northerly star, and the depression of a southerly one, increase as one heads towards the north, and so does the (altitude) of a southerly (star) as one heads towards the south.

٤و] وتركب[1] ما ذكرنا في الطول والعرض للذاهب في سمت بين السمتين. [ب ١٨٩ظ، ف ٢٥٤و]

[٥] أقول: ما ذكر لم يدل على تساوي الطول والعرض، فلم ينف الشكل البيضي وعكسه.

[٦] ففي[2] التحفة بين أولا كرية الأرض بما ذكرنا، ثم موازاة سطح الفلك سطحها بأن بلدين عرضهما واحد، وطولهما مختلف بمقدار، والمسافة بينهما مقدار، /وبلدين آخرين طولهما واحد وعرضهما مختلف [أ ٧ظ] بمقدار، والمسافة بينهما مقدار،[3] ونسبة المسافة إلى أجزاء الفلك، عرضا هنا وطولا ثمّة نسبة واحدة. [خ ٤ظ]

[٧] أقول: إن سلم أن أهل المساحة سووا بعض قطاع الأرض، وصدق قولهم إنهم [ج ٦ظ] وجدوا كذلك، لا يبعد أن تتفق بعض الأجزاء، بحيث تكون نسبة الطول والعرض فيها واحدة، [ف ٢٥٤ظ] دون المواضع الأخر. فيجب أن يضاف إليه شئ آخر وهو أن السائر إلى الشمال يتفاوت له ارتفاع القطب بقدر تفاوت انحطاط[4] الكوكب عن سمت الرأس. فلا يكون الفلك على شكل بيضي أو عكسه. [أ ٨و، ب ١٩٠و، هـ ٥و]

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[1] تركب: تركت [خ]

[2] ففي: وفي [ج]

[3] /و بلدين ... مقدار: العبارة، سقطت [ب]

[4] انحطاط: الانحطاط [ج]

Along intermediary directions, that which applies to longitude and latitude is compounded.

[5] I say: the above argument does not prove that the longitude and the latitude are equal, for it does not rule out the (possibility of having an) oval shape, or its reverse.

[6] In the *Tuḥfa*, the author proves the sphericity of the earth by the same (method) mentioned above. Next, (he proves) that the surface of the celestial orb is parallel to its (i.e. the earth's) surface by considering two localities whose latitudes are the same, and whose longitudes differ by some amount, while the distance between them is (yet) another amount; and by also considering two other localities whose longitudes are the same, their latitudes differ [f. 7v] by a certain amount, and the distance between them is still another amount; (he then found that) the ratio of the distance to the degrees of the celestial orb, whether (measured) in latitude or in longitude, will still be the same.

[7] I say: even if it be granted that land surveyors had leveled certain sectors of the earth, and even if what they said about their findings was true, it is still not unlikely that some parts may match, such that, (only) in these (parts), the ratio of the longitudes and latitudes are the same, to the exclusion of other localities. One additional point thus needs to be added, namely that, for one who is heading towards the north, the altitude of the pole changes by the same measure as the depression of a star away from the zenith does. Thus the celestial orb does not have an oval shape, nor does it have its reverse.

[٨] لكن يحتمل أن تكون الأرض كذلك، لأن ما قلنا أنه يجب أن يضاف إليه شئ يختص بالفلك. [خ ٥و] ثم الشواهد لا تفيد إلا التعريف لأنها لا تنفي أشكالا مضلعة قريبة من الكرة، ولا تضاريس غير محسوسة عند الأرض.[١]

[٩] وعلى كرية الماء بما يدل على كرية الأرض. فأذا كان بعض أجزاء سطحه قوس دائرة حول مركز العالم، يكون الكل كذلك، لكونه سيالا، فلا يكون بعضها[٢] [ف ٢٥٥و] أقرب إلى المركز [ج ٧و] وبعضها أبعد، بخلاف الأرض.

[١٠] وأما ظهور أعالي الجبال دون أسافلها[٣] فليس بشيء[٤] لأن الشيء يرى من البعيد أصغر، فيمكن أن يظن الرائي أن المرئي رأسه. وأيضا البخار المتصاعد في البحار يستر الأسافل.[٥] على أن مثل ذلك التقبيب في مثل تلك المسافات كالخط المستقيم، إذ لا تفاوت بينهما بحيث يحس.

[١١] /وإشكال تضاريس الأرض لا يرد على الطبيعي، لأنه يدعي

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[١] عند الأرض: العبارة، علي الهامش [أ]

[٢] بعضها: وبعضها [أ]

[٣] أسافلها: أسافله [أ، ب]

[٤] بشيء: شيء [ب]

[٥] الأسافل: الكلمة، سقطت [ج]

[8] [f. 8r] It is possible, however, that the earth is as such (i.e. it has an oval or a lenticular shape,) since the (above) reference (to) "one additional point (that) needs to be added," (actually) pertains to the celestial orb. Moreover, the (presented) evidence can only be used in a (theoretical) definition, since it does not negate (the possibility of having) polygons which are close to a sphere, nor (of having) indentations which are undetectable at (the surface of) the earth.

[9] The sphericity of (the surface of) water (is also inferred) from evidence similar to that which is given for the sphericity of the earth. If portions of its surface (i.e. that of the water) form an arc of a circle around the center of the world, then the whole (surface) is also so (i.e. a circle) on account of its fluidity. Thus, in contrast to the earth, no parts of (the water's surface) are closer or further away from the center.

[10] The fact that the peak of a mountain is visible, whereas its foot is not, is of no importance; since a distant object appears to be smaller, an observer might then think that (only) the tip is observed. Moreover, the vapor emitted from the seas obscures the bottoms (of mountains). In addition, such a convexity at such distances approximates a straight line, since there is no tangible difference between the two.

[11] The problem of the indentations of the earth does not occur to a natural philosopher, since he claims

أن البسيط لو خلي وطبعه يكون كريا. فظاهر[١] الأرض ليس بسيطا، وأيضا لم يخل وطبعه.

[١٢] وأما على الرياضي، فهو إن ادّعى أن مجموعها كرة حقيقية فليس كذلك.[٢] والعذر بأن ذلك لا يقدح في كريتها غير مسموع، لأن أي قليل فرض يقدح في ذلك.

[١٣] /وإن ادّعى أنها قربت من الكرة بحيث لا تختلف الأحوال الفلكية بحسب تضاريسها، فلهذا العذر وجه.

[١٤] وعلى أن الأرض في الوسط شرقا وغربا بتساوي زماني الارتفاع [ب ١٩٠ظ] والانحطاط لكوكب [أ ٨ظ، خ ٥ظ] يطلع و يغرب.[٣] وشمالا وجنوبا: بكون ظل الشمس على خط واحد وقت طلوعها وغروبها في نقطة الاعتدال، [ف ٢٥٥ظ] أو في نقطتين يتساوى بعدهما منها. [ج ٧ظ] /وفوقا وتحتا: بظهور[٤] نصف الفلك. وأعم من الكل بانخساف القمر في مقابلة الشمس بلا عرض.[٥] [هـ ٥ظ]

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[١] فظاهر: وظاهر [ج]

[٢] /و إشكال ... كذلك: العبارة، شرح [ج]

[٣] /وإن ادعى...يغرب: العبارة، شرح [ف]

[٤] بظهور: وظهور [ب]

[٥] /وفوقا ... عرض: العبارة، شرح [ب]

that a simple body, left to its nature, would be spherical. The surface of the earth, however, is neither simple, nor is it left to its nature.

[12] If, on the other hand, a mathematician claims that the resultant sphere is a real one, then that is not so. The justification that these (indentations) do not violate its sphericity carries no weight, since even the slightest assumed (indentations) would disprove this (sphericity).

[13] If it is claimed that it (i.e. the earth) approximates a sphere such that the (observed) celestial conditions do not vary as a result of its indentations, then that allegation has a rationale.

[14] That the earth is (located) midway between east and west, (is inferred) from the equality of the times of ascent and descent of a star [f. 8v] that rises and sets. (That the earth is located midway between) north and south, (is inferred) from the fact that the sun's shadows fall on the same straight line during its rising and setting at the equinox, or at two points which are equidistant from it. (That the earth is located midway between what is) above and (what is) below (is inferred) from the appearance of half of the celestial orb. More general than all (the above indications) is the eclipse of the moon when it is in opposition to the sun, while it has no latitude.

[١٥] وعلى أن ليس لها قدر محسوس عند بعض الأفلاك بعدم[١] اختلاف المنظر بالنسبة إلى العلويات.

[١٦] وعلى أنها ساكنة[٢] بوقوع الحجر المرمي في الهواء على موضعه. ومشايعة الهواء ليس بشيء، لعدم التفاوت بين الأثقل والأخف وبين حركة المتحركات إلى جهة المشايعة وخلافها.

[١٧] واعلم أن كون الأرض في الوسط بحيث يكون مركزها مركز العالم مشكل، لأن سطح البحر المحيط يجب أن يكون جميع أجزائه متساوي البعد من مركز العالم - وكذا سطح البحر مع سطح الأرض- أو أقرب [خ ٦و] إلى المركز، لئلا يحيط الماء بسطح الأرض. [أ ٩و] فمجموعها كرة واحدة، مركز المجموع مركز العالم.

[١٨] وما قيل إن حر الشمس في الحضيض[٣] يحدب الماء فليس بشيء، لأن أشد الحر لم ير قط مانعا للماء عن طبيعة السيلان في الأرض المستوية[٤] بلا حاجز، لا سيما حر الشمس. على أنها إذا زالت عن سمت الرأس ووصلت إلى الأوج [ب ١٩١و] كيف لا يسيل؟

[١٩] وكون سطح الماء مستديرا[٥] حول مركز العالم يوجب أن الإناء

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[١] بعدم: لعدم [ج]

[٢] ساكنة: سساكنة [ج]

[٣] الحضيض يحدب: الهيض يجذب [ج]

[٤] المستوية: المستوي [أ، ب، ج]

[٥] مستديرا: الكلمة، شطبت منها الألف [أ]

[15] That it (i.e. the earth) has no perceptible size as compared to some orbs, (is inferred) from the absence of parallax with respect to the upper (stars).

[16] That it is motionless (is inferred) from the falling of a stone, which is thrown (up) in the air, back onto its (original) position. The (talk about the) air's concomitance (with the earth) is to no avail, since there are no differences between a heavier and a lighter (object), and between the movements of the mobiles along with or opposite to the direction of concomitance.

[17] Note that it is problematic to consider that the earth is in the middle, such that its center is the center of the world, since all the parts of the surface of the surrounding ocean must be equidistant from the center of the world. And so is the case with the surface of the sea, together with that of the earth. Otherwise it (i.e. the surface of the sea) should be closer to the center, in order that the water would not surround the surface of the earth. [f. 9r] Their aggregate is thus one sphere, and the center of the resultant is the center of the world.

[18] The maintained argument, that the heat of the sun at perigee curves the water, is to no avail, since even the strongest heat, including that of the sun, was never observed to deprive water, in a leveled land with no obstacles, of the nature of fluidity. If, moreover, it (i.e. the sun) passes beyond the zenith, and arrives at the apogee (sic), then how could (the water) not flow?

[19] The fact that the surface of the water is spherical around the center of the world, entails that a vessel

المملوء ماء إذا كان في قعر بئر فماؤه أكثر مما كان على رأس منارة، فإن الدائرة [ف ٢٥٦و] إذا كانت أصغر كانت أشد تقبيبا. [ج ٨و] وهذا مما يستغرب.

[٢٠] والمشهور أن عند مركز الأرض طبقة الأرض الخالصة. ثم فوقها الطبقة الطينية. ثم طبقة الأرض المخالطة بغيرها. ثم الماء المحيط بأكثرها. ثم الهواء الكثيف المجاور للماء والأرض. ثم الطبقة الزمهريرية التي تنشأ فيها السحب ونحوه. ثم طبقة الهواء الغالب التي تحدث فيها الشهب. ثم طبقة الممتزج من الهواء والنار التي تتلاشى فيها الأدخنة وتكون[١] فيها ذوات الأذناب ونحوها. ثم النار الصرف.

[٢١] فكرة الهواء باعتبار مخالطة الأبخرة وعدمها صار قسمين: أحدهما هواء لطيف صاف عن الأبخرة، ساكن لا يقبل النور والظلمة والألوان، كالفلك. والثاني هواء كثيف يسمى كرة البخار وعالم النسيم، [خ ٦ظ] وقدر بقريب[٢] سبعة عشر فرسخا. وهذه الزرقة إنما هي فيها بأن[٣] الأجزاء القريبة من سطحها أقل ضوءا[٤] من الأجزاء القريبة /إلى

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[١] تكون: تتكون [ج]

[٢] بقريب: +«ثخنه وقدره»، على الهامش [ب]

[٣] بأن: فإن [ج]

[٤] ضوءا: ضواء [أ]

filled with water would have more water when placed in the bottom of a well, than it would have when placed at the top of a minaret, since the smaller a circle is, the bigger its convexity will be. This (idea), however, is often found strange.

[20] It is generally accepted that the layer of pure earth is at the center of the earth. Above it is the clayish layer. Next comes the earth layer which is mixed with other (layers). Then the (layer) of water which surrounds most of it (i.e. the earth). Next is the dense air which is adjacent to the water and the earth (layers). Then the layer of bitter coldness (*zamharīr*) in which clouds and the like are generated. Next the layer which is predominantly air, in which luminous meteors originate. Then the mixed layer of air and fire in which vapors dissolve, and in which comets and the like are found. Then (the layer) of pure fire.

[21] The sphere of air is divided into two kinds in regard to the mixing or non-mixing of vapors: the first is a thin air which is clear of vapors, motionless, and admitting neither light nor darkness nor colors as (is the case with) the orbs. The second is dense air, called the sphere of vapor and the world of breeze, whose (height) is estimated at about seventeen leagues. The blueness is located in it because the parts (of this layer) which are closer to its upper surface are less bright than the parts which are close to

الأرض، فتكون مظلمة بالنسبة[١] إليها. فاذا نفذ[٢] نور البصر من الأجزاء القريبة[٣] المستنيرة بأشعة الشمس أو الكواكب إليها،[٤] رآها الناظر في لون متوسط بين النور والظلمة، وهو الزرقة.

[٢٢] ثم فوق النار الأفلاك، وترتيبها [أ ٩ظ] وعددها عرف من اختلاف حركات الكواكب، وكسف بعضها بعضا، واختلاف المنظر، [هـ ٦و] واختلاف منطقة الحركة الأولى والثانية.

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[١] /إلى الأرض ... بالنسبة: العبارة، تكررت ثم شطب التكرار [أ]

[٢] نفذ: لقد [ج]

[٣] /إلى الأرض ... القريبة: العبارة، على الهامش [ج]

[٤] إليها: الكلمة، سقطت [ج]

the earth. Thus the former are dark with respect to the latter. If the light of vision pierces through the parts close (to the earth), which draw their light from either the sun or the planets, and reaches it (i.e. the upper layer), then the observer will see a color intermediate between brightness and darkness, and that is the blueness.

[22] Above the fire (layer) are the planets (and the stars), whose configuration and number are known from the differences between the motions of the planets, the (planets') eclipsing of one another, the parallax, and the differences in the regions of the first and second motions.

[١] فصل في الدوائر.

[٢] الفلك الأعظم يتحرك من المشرق إلى المغرب، ويحرك الكل على قطبين ومنطقة، أي دائرة بعد جميع أجزاء محيطها من القطبين سواء. فتكون عظيمة، أي منصفة للفلك، وتسمى معدل النهار. دوره في قريب يوم وليلة، إذ هما دوره مع حركة الشمس. [ف ٢٥٦ظ] والدوائر الصغار الموازية له تسمى المدارات اليومية.

[٣] وفلك الثوابت، ويسمى فلك البروج، يتحرك من المغرب الى المشرق، ودوره في ستة[١] وثلاثين ألف سنة[٢] شمسية عند المتقدمين، وأربعة وعشرين ألفا عند المتأخرين، على قطبين. ومنطقته[٣] تسمى منطقة البروج، وهي مع معدل النهار، إذا[٤] فرضتا على فلك واحد لا يتحدان، بل يتقاطعان على نقطتين: إحديهما هي التي إذا جازها الكوكب [ب ١٩١ظ] على التوالي، أي من المغرب إلى المشرق، صار شماليا عن المعدل. [ج ٨ظ] والأخرى مقابلة لها، وهي ما يصير جنوبيا. فتلك وهذه نقطتا[٥] الاعتدال الربيعي والخريفي. ومنتصفا النصف

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[١] ستة: سنة [ج]

[٢] ألف سنة: الفرسية [ج]

[٣] منطقته: منطقة [ج]

[٤] إذا: إذ [ج]

[٥] نقطتا: نقطتان [ب]

[1] Chapter [3]: On Circles.

[2] The great orb moves from the east to the west, and moves the whole around two poles and a cincture (*minṭaqa*), the latter being a circle whose circumference is such that all its points are equidistant from the two poles. It is thus a great (circle), that is one which bisects the celestial sphere, and it is called the equator. Its (i.e. the great orb's) rotation takes place in one day and night approximately, for these (i.e. the day and the night) are the sum of its own rotation as well as the movement of the sun. The small circles parallel to it (i.e. the equator) are called day circles.

[3] The orb of the fixed stars, which is called the ecliptic orb, moves from the west to the east around two poles. Its revolution according to the ancients, is in thirty six thousand solar years, while according to the moderns, it is twenty four thousand. Its cincture is called the zodiacal belt. If it (i.e. the zodiacal belt) and the equator were assumed to fall on the same orb, then they do not coincide, rather they intersect at two points: the first (point) is such that when a planet, (rotating) in the direction of the sequence (of the zodiacal signs), that is from the west to the east, crosses it, (then this planet) passes to the north of the equator. The other (point) is diametrically opposite to it (i.e. to the first point), and (when the planet crosses) it, (this planet) passes to the south (of the equator). These two (points) are (respectively) the vernal and the autumnal equinoctial (points). The midpoints of

الشمالي والجنوبي من المنطقة[1] نقطتا الانقلاب الصيفي والشتوي.

[٤] ثم قسم كل ربع بنقطتين أخريين بثلاثة أقسام متساوية وأدير ست دوائر عظام تتقاطع على قطبي البروج. أحدها[2] [خ ٧و] يمر بالمنقلبين، وهي المارة بالأقطاب الأربعة. فالقوس منها بين[3] المعدل والمنطقة الميل الكلي، وغاية الميل، وكذا بين القطبين. وقد وجدته كجـ[4] لجـ، كما في الزيج العلائي. فحصل إثنا[5] عشر برجا، طوله من دائرة إلى دائرة، وعرضه من قطب إلى قطب.

[٥] ويجب أن يعلم أن فلك البروج، وإن كان هو المتحرك حركة ثانية ومنطقة البروج منطقته، لكن يرتسم مع البروج على الفلك الأعظم لئلا تختلف بالحركة الثانية، ولتنتقل الثوابت من برج إلى برج. [أ ١٠و، ف ٢٥٧و] والثوابت، وكل نقطة على فلك البروج، لا يختلف وضعها بالحركة الثانية بالنسبة إلى منطقة البروج، وإن كان يختلف بالنسبة إلى أقسام البروج وإلى[6] معدل النهار.

[٦] وكل كوكب على المنطقة يقطع المعدل في دورة من الحركة الثانية

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[1] المنطقة: +«أي المنطقة البروج»، فوق السطر [أ]

[2] أحدها: أحديها [أ، ج، خ]، إحداها [ب]

[3] بين: +«على»، قبلها [ج]

[4] كجـ: جـ [ج]

[5] إثنا: إثنتي [ج]

[6] وإلى: الكلمة، سقطت [ج]

the northern and southern halves of the (zodiacal) belt are (respectively) the summer and the winter solstices.

[4] Then each quadrant (of the ecliptic) is divided into three equal parts by two more points. Six great circles are drawn so that they intersect at the two poles of the ecliptic. One of these (circles) will then pass through the two solstices, and this will be the same as the one that passes through the four poles. The arc of this (circle), which lies between the equator and the (zodiacal) belt, is the total declination, and is the extreme limit of the inclination (of the ecliptic), and so is (the arc) between the two poles. This (arc) I found to be 23;33 (degrees), as in the *'Alā'ī zīj*. Thus twelve zodiacal signs are obtained, (each stretching) in longitude from one circle to the next, and in latitude between the two poles (of the ecliptic).

[5] It should be noted that, even if the zodiacal orb is the one which moves in a second motion, and although the zodiacal belt is its own cincture, it still ought to be drawn with the zodiacal on (the surface of) the great orb, so that (the signs) would not vary as a result of the second motion, and so that the fixed stars could move from one sign to another. [f. 10r] Moreover, the positions of the fixed stars, and of every point on the zodiacal orb, do not vary with respect to the zodiacal belt, as a result of the second motion, although they do vary relative to the divisions of the zodiacal signs, and to the equator.

[6] As a result of the second motion, each star that falls on the cincture crosses the equator twice during one revolution,

مرتين، وكذا ما يكون عرضه أقل من الميل الكلي. لكن تختلف قطعتا مداره الجنوبية والشمالية، ويكون أعظمها ذات جهة العرض. [أ ١٠ظ، ب ١٩٢و، ج ٩و، ف ٢٥٧ظ، هـ ٦ظ، خ ٧ظ] وما يساوي عرضه الميل الكلي يماسه على المنقلب الذي في جهة عرضه. [خ ٨و] وما يفضل لا يقطع ولا يماس بل يقرب ويبعد. [ج ٩ظ] وإن كان مساويا لتمام الميل الكلي ينتهي إلى قطب المعدل[١] مرة. وبحسب هذا الاختلاف تختلف المدارات[٢] اليومية، فينتقل الكوكب من مدار أصغر إلى أكبر،[٣] وبالعكس.

[٧] وتختلف أوضاع الكواكب [ب ١٩٢ظ] بالنسبة إلى البقاع على ما يأتي في السفليات.

[٨] دائرة الأفق هي الفاصلة بين النصف الظاهر والخفي من الفلك، وقطباها سمت الرأس [ف ٢٥٨و] والقدم. [أ ١١و] ونقطتا[٤] التقاطع بينها وبين المعدل نقطتا المشرق و المغرب. والخط الواصل بينهما خط المشرق والمغرب، والدوائر الصغار الموازية لها المقنطرات.

[٩] الدوائر المارة على سمت الرأس والقدم إن مرت[٥] على نقطتي

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[١] المعدل: +«من المنطقة إلى قطب المعدل»، على الهامش [ب]

[٢] المدارات: المدارلت [ج]

[٣] أكبر: أكثر [ج]

[٤] ونقطتا: ونقطتا [ج]

[٥] مرت: قرب [ج]

and so does (a star) whose latitude is less than the total declination. The southern and northern sections of this (latter kind), however, differs in size, the greater of which is the one in the direction of the latitude. [f. 10v] (A star) whose latitude is equal to the total declination, is tangent to it (i.e. the equator) at the (side of the) solstice which is in the same direction as the (star's) latitude. (Stars whose latitude) exceeds (the obliquity of the ecliptic) neither intersect nor become tangent to (the equator), rather they approach and recede (from it). If, on the other hand, (the latitude of a star) is equal to the complement of the total declination, then it (i.e. the star) would reach the pole of the equator only once. The day circles thus differ in accordance with the above variations, and the stars move from a smaller to a bigger day circle, and vice versa.

[7] The apparent positions of the stars also vary relative to (different) localities, as will be mentioned in (the section on) the sublunar region.

[8] The horizon circle is the one which separates the visible and hidden parts of the celestial sphere. Its two poles are the zenith and the nadir. [f. 11r] The two points of intersection between it and the equator are the east and west points. The small circles parallel to it (i.e. to the horizon) are the altitude circles (*almuqanṭarāt*).

[9] If a circle passing through the zenith and the nadir also passes through

المشرق والمغرب فدائرة أول[1] السموت، [هـ ٧و] وعلى قطبي العالم دائرة نصف النهار. وتقطع دائرة الأفق على نقطتي الشمال والجنوب. والخط الواصل بينهما خط نصف النهار. والقوس منها بين سمت الرأس والمعدل، أو بين الأفق والقطب عرض البلد. [خ ٨ظ] وعلى قطبي البروج وسط سماء الرؤية. وعلى أي نقطة تفرض دائرة الارتفاع. فالقوس منها بين الأفق [ج ١٠و] وتلك النقطة ظاهرةً ارتفاعها، وخفيةً انحطاطها. وسمت الكوكب قوس من دائرة الأفق بين دائرة ارتفاعه وأول السموت. وسعة مشرقه قوس منها بين مطلعه ونقطة المشرق. وسعة مغربه قوس منها بين مغربه ونقطة المغرب.

[١٠] دائرة الميل دائرة تمر بقطبي العالم. فالقوس منها بين المعدل والكوكب بعده عنه. وبينه وبين أجزاء منطقة البروج ميلها الأول. وبينهما من دائرة العرض، أي المارة بقطبي البروج، ميلها الثاني. [أ ١١ظ، ب ١٩٣و، ف ٢٥٨ظ] ففي المنقلبين يتحد الميلان، وهما قوس من المارة، وفي غيرهما لا. والميل الثاني أكثر لأنه وتر القائمة. [خ ٩و] والقوس منها بين الكوكب والمنطقة عرضه.

[١١] ثم اعلم أن الميل الكلي وجد في كل رصد أقل مما وجد قبل. لكن اختلافا غير مضبوط. فيمكن أن يكون الاختلاف لعدم صحة آلات الرصد، لكن الأقرب أن عدم الضبط لذلك السبب.

[١٢] [ج ١٠ظ] فقيل منطقة الحركة الثانية تتحرك عرضا. فأما أن

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[1] أول: أولا [هـ]

the east and west points, then this will be the prime vertical. If, on the other hand, it passes through the two poles of the world, then this will be the meridian circle. (The meridian circle) intersects the horizon circle at the north and south points. The line joining these two (points) is the line of midday. The arc of this (meridian) circle, which falls between the zenith and the equator, or between the horizon and the pole (of the equator) is the terrestrial latitude. If (the circle passing through the zenith and the nadir also) passes through the two poles of the ecliptic, then this will be the mid-heaven arc of visibility (*wasaṭ samā' al-ru'ya*). (Finally), if it passes through any given point (on the celestial orb), then this will be the altitude circle. An arc of this circle, which falls between the horizon and that given point, will be its altitude if it (i.e. the point) is visible; if it is hidden, then (the arc) will be its depression. The azimuth of a star is the arc of the horizon circle which falls between its altitude circle and the prime vertical. The rising amplitude is the arc of this (horizon circle), which is between the (star's) rising point and the east, whereas the setting amplitude is the arc which is between its setting point and the west.

[10] The declination circle is a circle which passes through the two poles of the world. An arc on it which is between the equator and the star is the distance of the latter from the former, and the arc between (the equator) and the (corresponding) part of the ecliptic is (that part's) first declination. The arc between the two (circles, i.e. the equator and the ecliptic), along the latitude circle, which is the circle passing through the two poles of the ecliptic is its (i.e. the part's) second declination. [f. 11v] The two declinations coincide at the two solstices, both being one arc of the (circle) passing (through the four poles). At any point other than the solstices, (the two declinations) do not (coincide). The second declination is greater, being the hypotenuse of a right angle. (On the other hand), the arc of (the latitude circle), between the star and the ecliptic, is (the star's) latitude.

[11] Note that the total declination has been found to be successively smaller in each successive observation. The variations, however, are not uniform. And although the variations could result from errors in the observational instruments, yet it is more likely that the lack of uniformity is due to that same reason (i.e. the progressive reduction of the total declination).

[12] It has been maintained that the cincture of the second motion moves in latitude. It (i.e. the cincture) may

تتم الدورة[١] أو لا، بل ترجع بعد الانطباق[٢] الثاني على المعدل، أو عنده،[٣] أو قبله بعد[٤] قطع نصف الدور، أو عنده،[٥] أو قبله بعد الانطباق الأول، أو عنده،[٦] أو قبله.[٧] ففي الثلاثة الأول ينطبق كل نصف من المنطقة على كل نصف من المعدل. [ف ٢٥٩و، هـ ٧ظ] وفي الخمسة الأولى يتبادل[٨] كل من نصفي كرة البروج، أي الشمالي والجنوبي. [أ ١٢و، ب ١٩٣ظ، خ ٩ظ] وفي الثلاثة الأخر يتبادل[٩] بعضه. وفي السبعة الأول ينطبق نصف المنطقة على النصف المجاور له من المعدل. وفي كل انطباق يتساوى الليل [ج ١١و] والنهار في جميع البقاع، وتبطل فصول السنة. [ف ٢٥٩ظ] واستثنى في التحفة الأفق الرحوي. وفي الثامن تختلف الارتفاعات[١٠] ومقادير الأيام. [خ ١٠و] ومحركه يعرف في فصل العرض.

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[١] الدورة: +١، فوق السطر [أ]

[٢] بعد الانطباق: +٢، فوق السطر

[٣] عنده: +٣، فوق السطر [أ]

[٤] بعد: +٤، فوق السطر [أ]

[٥] عنده: +٥، فوق السطر [أ]

[٦] عنده (الثانية): +٧، فوق السطر [أ]

[٧] قبله: +٨، فوق السطر [أ]

[٨] يتبادل: يتناول [خ]

[٩] يتبادل: يتناول [خ]

[١٠] الارتفاعات: ارتفاعات [ج]

or may not move one complete revolution. In the latter case (the cincture) reverses its motion (first) after the second coincidence with the equator, or just at it (i.e. at the second coincidence with the equator); (second) before (the second coincidence with the equator), after half a revolution having been completed, or just at (its completion); and (third) before (the completion of half a revolution), after the first coincidence (with the equator), or just at it (i.e. at the first coincidence), or before (this first coincidence). In the first three (cases) each half of the cincture coincides with each half of the equator. In the first five (cases) each of the two halves of the celestial sphere, that is the eastern and western (halves), interchanges, [f. 12r] while in the remaining three only parts of it would. In the first seven (cases) half the cincture coincides with the part of the equator which is adjacent to it. During every coincidence, day and night at all localities are equal, and the seasons of the years cease. In the *Tuḥfa*, however, the horizon where the motion is like that of a millstone (*raḥawī*), is excluded. In the eighth (case) the altitudes (of stars) and the lengths of days vary. The mover (of this second motion) will be further determined in the forthcoming chapter on latitudes.

[١٣] وقيل، ولا اعتماد عليه، أن لفلك البروج إقبالا وإدبارا بقدر ثماني درجات في ستمائة وأربعين سنة. [أ ١٢ظ] فتسرع الحركة الثانية بالإقبال، وتبطء بالإدبار. فإن صح ذلك فلابد له من محرك. فقيل يكفي لذلك ولمحرك[١] الميل فلك واحد، بأن يفرض حاويا لفلك البروج، قطباه [هـ ٨و] على الدائرة المارة، بعدهما عن قطبي البروج أربع درجات؛ فيتحرك قطب البروج على دائرة صغيرة قطرها ثماني درجات. وإذا[٢] تحرك القطب يحرك[٣] كل نقطة من فلك البروج، فيرتسم من دورانها دائرة صغيرة مساوية للمذكورة، يكون من الحركة في أحد نصفيها الإقبال، ومن الآخر الإدبار. [ب ١٩٤و، ف ٢٦٠و] /ومن الحركة من منتصف أحد النصفين إلى منتصف الآخر انتقاص الميل، وفي الآخر ازدياده.[٤]

[١٤] [ج ١١ظ] لكن هذا غير صحيح، لأن انتقاص الميل ليس بهذا القدر في تلك المدة. وأيضا ارتسام الصغيرة خطأ، بل يرتسم من كل نقطة دائرة موازية لمنطقة المحرك.

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[١] ولمحرك: +«الفلك»، ثم شطبت [ب]

[٢] وإذا: فأذا [ج]

[٣] يحرك: حرك [ب]

[٤] /ومن الحركة ... ازدياده: العبارة، شرح [ب]

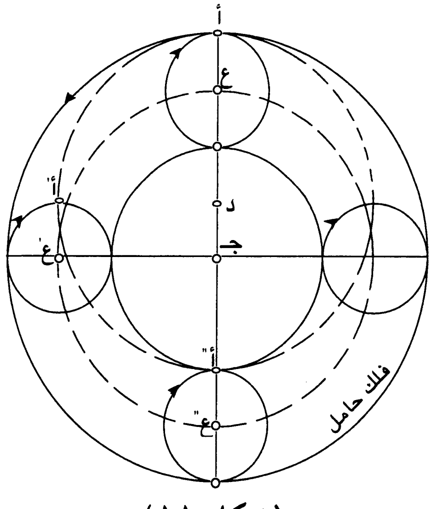
[13] It has been maintained, although unreliably, that the celestial orb has a forward and a backward motion amounting to eight degrees in six hundred and forty years. [f. 12v] The second motion thus becomes faster when forward, and slower when backward. Were this to be true, then an (additional) mover would be needed. It was suggested that one orb would be enough for this latter (mover) and for the mover of the inclination, if we were to assume that the celestial sphere has an encompassing orb whose poles fall on the circle passing (through the ecliptic orb), such that they are four degrees away from the poles of the ecliptic; the pole of the ecliptic would thus move on a small circle whose diameter is equal to eight degrees. When the pole moves, it would move every point on the celestial sphere, and a small circle which is equal to the above mentioned one would be generated as a result of its rotation (i.e. the rotation of the pole). Forward (motion) would then result from the movement along one of its (i.e. the circle's) two halves, whereas the backward (motion) would result from (the movement along) the other half. Moreover, the inclination would decrease during the movement from the midpoint of one of the two halves to the midpoint of the other, and it would increase in the other (half).

[14] The above hypothesis, however, is not correct, because the reduction in the inclination over this period is not equal to the (above mentioned) quantity. Moreover, the tracing of the small circle is erroneous, rather, a circle parallel to the cincture of the mover would be generated at every point (of the great orb).

[١] [خ ١٠ظ] فصل: في فلك الشمس.

[٢] وجدت في نصف فلك البروج سريعة، وفي نصفه بطيئة. وفي الكسوفات في منتصف زمان البطء أصغر قليلا منها في منتصف زمان السرعة. [أ ١٣و] فتكون في زمان البطء أبعد عن الأرض.

[٣] فهي إما على فلك غير شامل للأرض، يسمى تدويرا، يماس سطحه سطحها، في ثخن فلك حامل مركزه مركز العالم، تماس نقطة من سطحه نقطة من محدب حامله، ونقطة منه نقطة من مقعره، ويتم دورهما[١] معا،[٢] /وحركة أسفل التدوير على التوالي.[٣] [ف ٢٦٠ظ]



(شكل ١١)

[١] دورهما: دورها [ب]

[٢] معا: الكلمة، على الهامش [ج]

[٣] وحركة...التوالي: العبارة، شرح [ف]

[1] Chapter [4]: On the Orb of the Sun.

[2] It (i.e. the sun) was found to be fast in one half of the ecliptic orb and slow in the other. During solar eclipses it is a little smaller at the middle of the period of slow (motion) than at the middle of the period of fast (motion). [f. 13r] It (i.e. the sun) should then be farther away from the earth during the period of slow (motion).

[3] Therefore, it (i.e. the sun) falls: (1) either on an orb which does not encompass the earth, and which is called an epicycle, whose surface is tangent to the surface (of the sun); (moreover, the epicycle) is (embedded) in the thickness of a deferent orb whose center is the center of the earth, such that a point on its surface (i.e. the surface of the epicycle) is tangent to a point on the convex surface of its deferent, while (another) point (on the surface of the epicycle) is tangent to a point on the concave surface (of the deferent). Their revolutions (i.e. that of the epicycle and the deferent) are completed at the same time. The motion of the lower (half) of the epicycle is in the direction of the sequence of the signs.

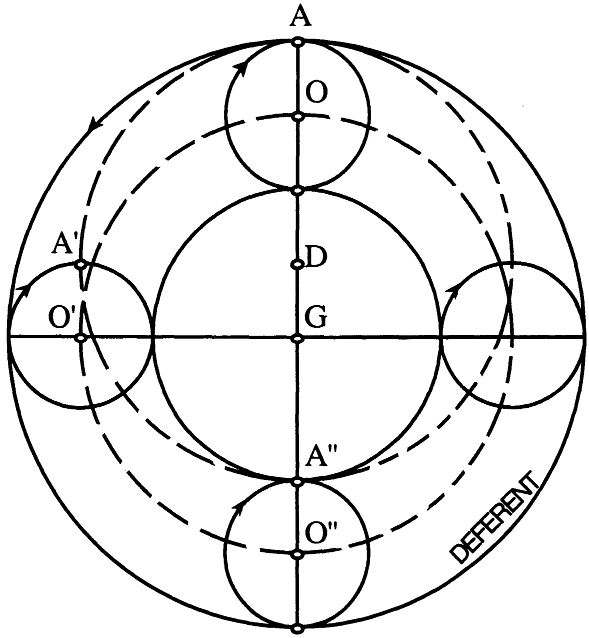
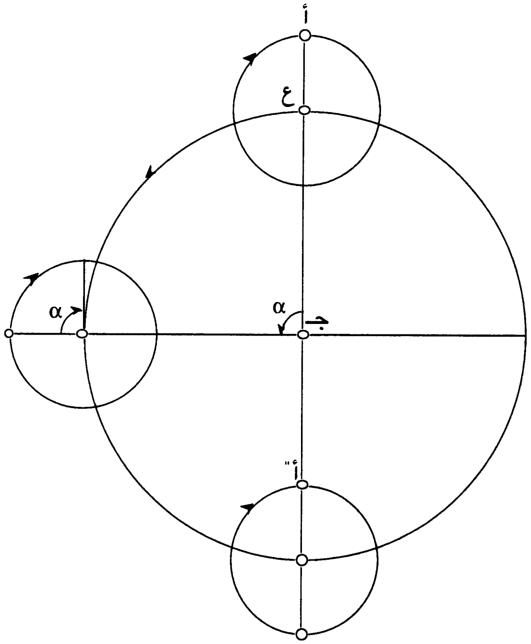


FIGURE 11



(شكل ١٢)

[٤] وإما على خارج [ج ١٢و] مركز شامل للأرض، في ثخن فلك مركزه مركز العالم، يسمى الممثل، [خ ١١و] أي بفلك البروج، لكون منطقته في سطح منطقته؛ يماس محدبه محدبه على نقطة [ب ١٩٤ظ] هي الأوج، ومقعره مقعره على نقطة هي الحضيض. أي ما يحتاج إليه من[1] الممثل هذا القدر، فانه يمكن أن يكون زائدا على هذا، [هـ ٨ظ] وكذا في التدوير والحامل. [أ ١٣ظ]

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[1] من: في [ج]

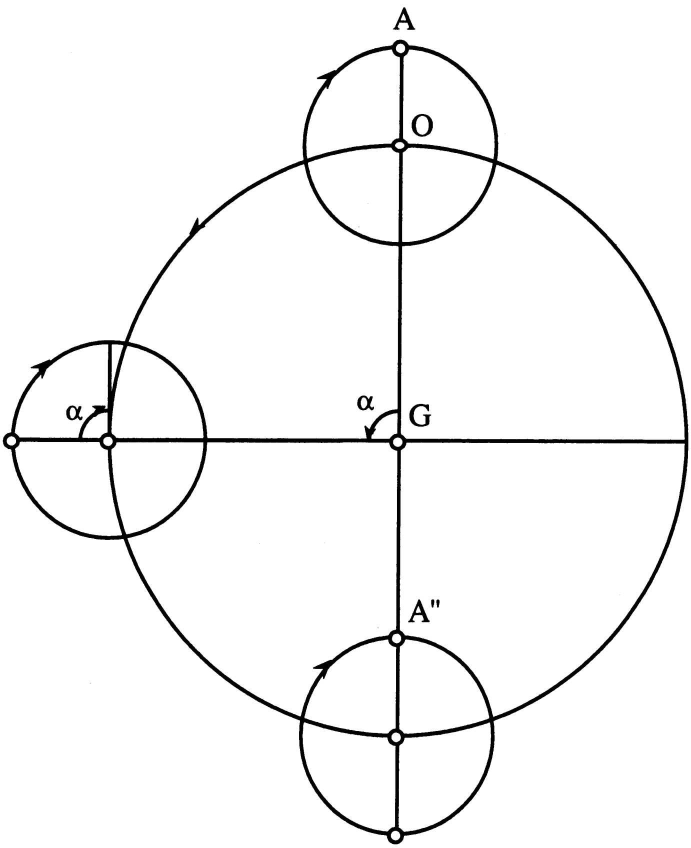
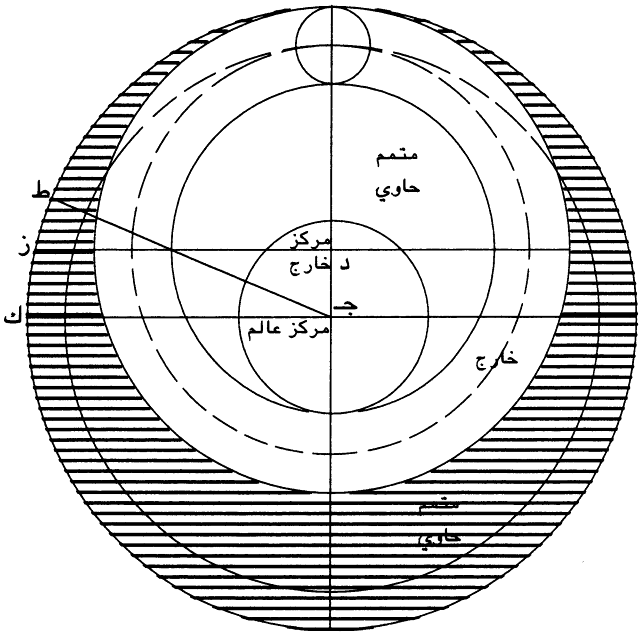


FIGURE 12

[4] (2) Or on an eccentric (orb) which encompasses the earth, and which is embedded in the thickness of an orb whose center is the center of the earth. This (latter orb) is called the parecliptic orb, that is (the one simulating) the ecliptic orb, since the cincture of one is on the surface of the cincture of the other. The convex surface (of the eccentric circle) is tangent to the convex surface (of the parecliptic) at a point called the apogee, and their concave surfaces are tangent at a point called the perigee. This, however, is the (minimum) dimension required for the parecliptic, although it is possible that it may exceed this (dimension), and (this is) equally (possible) in (the case of) the epicycle and the deferent.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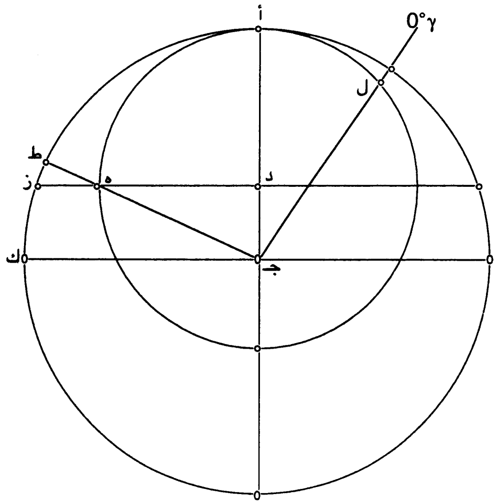
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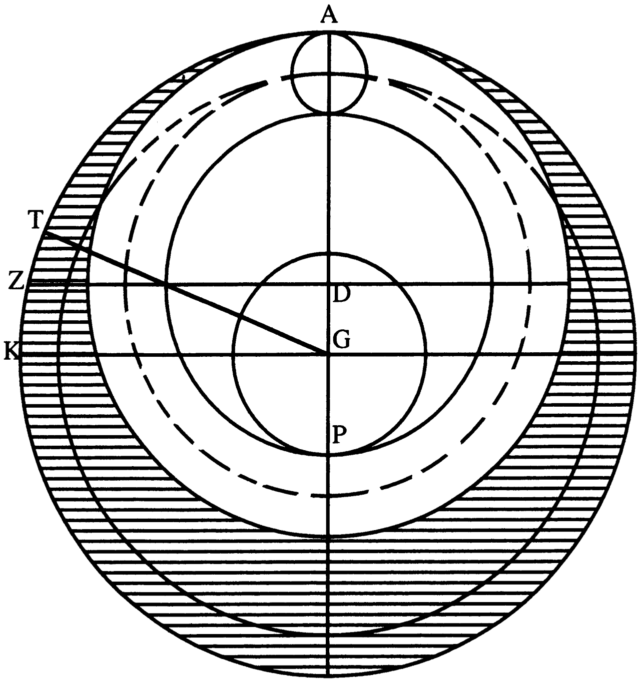

FIGURE 13

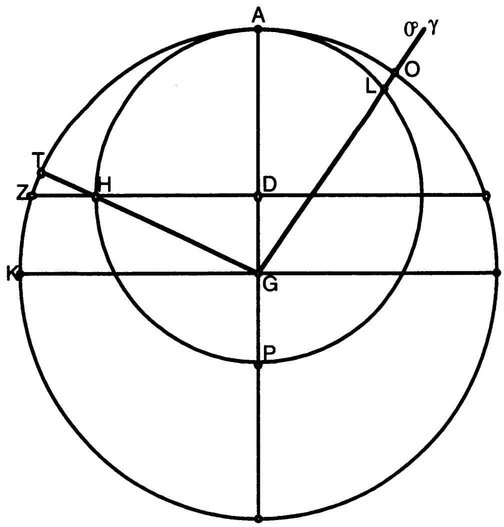

FIGURE 14

[٥] فيبقى جسمان مختلفا الثخن يسميان[١] المتممين، أحدهما حاو لخارج المركز، والآخر محوي؛ رقة الحاوي في طرف الأوج، وغلظه في طرف الحضيض، والمحوي على العكس.

[٦] وقد[٢] قيل اختار بطليموس هذا لأنه أبسط من التدوير، لأن دور [ف ٢٦١و] التدوير يستلزم مدار خارج المركز، وهو لا يستلزم التدوير. أقول بل على العكس، إذ على تقدير التدوير يجب جسمان: هو وحامله، وعلى تقدير الخارج ثلاثة: هو والمتممان، على أنهما بعيدان[٣] جدا عن البساطة.[٤] فهو إنما اختاره لأنه كان يقتصر على الدوائر، فهو أبسط للمقتصر، لا لمن أثبت الأفلاك المجسمة.

[٧] [ب ١٩٥و، ج ١٢ظ، خ ١١ظ] فالقوس من الممثل، بين أول الحمل إلى نقطة الأوج، تسمى أيضا بالأوج. ثم منه إلى طرف خط من مركز الخارج إلى مركز الشمس، تسمى بالمركز، وهو كل يوم ، نط[٥] ح ك. ومجموع قوسي الأوج والمركز وسط. فأن أخرج خط من مركز العالم إلى مركز الشمس، ومنه إلى الممثل، فمن أول الحمل إلى طرفه تقويم؛ وما بين الوسط والتقويم تعديل، وهو زاوية على مركز الشمس بين الخطين

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[١] يسميان: يسميا [أ]

[٢] قد: الكلمة، سقطت [ج]

[٣] بعيدان: بعيدين [ب]

[٤] البساطة: البسايط [ج]

[٥] ح نط: نط [ب]

[5] [f. 13v] (In the eccentric model), two solids of different thicknesses result. These are called the complementary (solids). One of them encompasses the eccentric orb, whereas the other is encompassed (by it). The thinness of the encompassing (complementary solid) is at the point of the apogee, while its thickness is at the point of the perigee, and conversely for the encompassed (complementary solid).

[6] It is maintained that Ptolemy chose this (eccentric model) because it is simpler than the epicyclic (model), since the rotation of the epicycle requires an eccentric orb, whereas the latter (i.e. the eccentric orb) does not require an epicycle. I say, however, that it is the other way round, since with the assumption of the epicycle, two solids are required, namely it (i.e. the epicycle) and its deferent, whereas with the assumption of the eccentric, three (solids are required), namely it (i.e. the eccentric orb) and the two complementary solids, and these are indeed very far from simplicity. He (i.e. Ptolemy) only chose it (i.e. the eccentric model) because he confined himself to (plane) circles, and it (i.e. the eccentric model) is only simpler for such a confiner, while it is not (simpler) for one who posits (the existence of) solid orbs.

[7] The arc of the parecliptic, (falling) between the first (point) of Aries and the point of the apogee, is also called the apogee. (The arc of the parecliptic, extending) from it (i.e. the apogee) to the extremity of a line (issued) from the center of the eccentric to the center of the sun, is called the (mean) center, and it (increases by) 0;59,8,20 (degrees) per day. The sum of the apogee and center arcs is the mean (longitude). If a line is then issued from the center of the world to the center of the sun, and through it to the parecliptic, then (the arc extending) from the beginning of Aries to its (i.e. the line's) extremity is the true position; the difference between the mean and the true position is the equation, that is an angle at the center of the sun (subtended) between the two

المذكورين. [أ ١٤و] وهو ناقص من الوسط مادامت الشمس هابطة من الأوج، زائد مادامت صاعدة.

[٨] وغايته [خ ١٢و] ما يقتضيه ما بين المركزين، [ف ٢٦١ظ، هـ ٩و] وما بينهما عند [ج ١٣و] بطليموس ب ل ، وعند المتأخرين ب ه، على أن نصف قطر الخارج ستون. وإن كانت الشمس على الأوج أو الحضيض فلا تعديل.

[٩] وفي صورة التدوير يكون نصف قطره بقدر ما بين المركزين هنا.

[١٠] هذا ما قيل في كتب الهيئة؛ [ب ١٩٥ظ] يرد[١] عليه إشكال، وهو أن التعديل الذي يزاد أو ينقص ليحصل التقويم ليس الزاوية المذكورة، بل هي مع شيء آخر. وذلك لأن الخارج إذا حرك الشمس ثلاثة[٢] بروج مثلا من نقطة الأوج، فخرج[٣] خط من مركز الخارج، وهو نقطة[٤] د، إلى مركز الشمس، وهو نقطة[٥] ه، ووصل إلى ز من منطقة الممثل، وخط آخر [ف ٢٦٢و] من مركز العالم، وهو جـ،[٦] إلى مركز الشمس، ووصل إلى ط من منطقة الممثل، وخط آخر من جـ مواز لخط د ز، ووصل إلى كـ من المنطقة،

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[١] يرد: ويرد [ج]

[٢] الشمس ثلاثة: الثلاثة [ب]

[٣] فخرج: يخرج [ج]

[٤] نقطة: نقط [ج]

[٥] نقطة: نقط [ج]

[٦] جـ: غير واضحة [ب]

above mentioned lines. [f. 14r] It (i.e. the true position) is less than the mean, when the sun is descending from the apogee, and greater when ascending.

[8] The maximum (value of the solar equation) is determined by the distance between the two centers. (The distance) between them (i.e. the two centers), according to Ptolemy, is 2;30 (parts), whereas according to the moderns it is 2;5 (parts), assuming that the radius of the eccentric is 60 (parts). Moreover, when the sun falls at either the apogee or the perigee, the anomaly ceases to exist.

[9] In the case of the epicycle, the radius (of the epicycle) is equal to the distance between these two centers.

[10] This is what is maintained in the books of astronomy. An objection may be raised against it, namely that the equation which should be added or subtracted in order to obtain the true position is not the (above) mentioned angle, rather it is something else. This is so because (of the following): let, for example, the eccentric move the sun (a distance of) three zodiacal signs away from the apogee; let the line issued from the center of the eccentric, namely point *D*, to the center of the sun, namely point *H*, reach (a point) *Z* on the cincture of the parecliptic; let another line (issued) from the center of the world, namely (point) *G*, to the center of the sun reach (a point) *T* on the cincture of the parecliptic; and let one more line (issued) from (point) *G* parallel to line *DZ* reach (a point) *K* on the cincture (of the parecliptic).

فالقوس الواقعة[١] من الأوج إلى ز ربع منطقة الخارج. فموضع الشمس من الممثل بالنسبة إلى مركز العالم نقطة ط. فالقوس [أ ١٤ظ] من الأوج إلى ط، إن أردنا أن نقدرها من منطقة الممثل، يجب أن ننقص من ربع الممثل قوس ط ك، ولا يكفي نقصان ط ز، وهو وتر زاوية التعديل.

[أ ١٥و، ب ١٩٦و، ج ١٣ظ، ف ٢٦٢ظ، هـ ٩ظ، خ ١٣و]

[١١] أقول عنه جوابان:[٢] (١)[٣] الغرض في الهيئة تعيين موضع الشمس بالنسبة إلى مركز العالم. فأن موضعها بالنسبة إلى مركز الخارج ز، وبالنسبة إلى مركز العالم ط. فأذا نقص قوس زط من الوسط تعين موضعها بالقياس إلى مركز العالم. والمذكور في الزيجات لبيان نسبة القوس التي قطعت إلى منطقة الممثل.

[١٢] (٢)[٤] إن المذكور في كتب[٥] الهيئة يمكن أن يراد به المثبت في الزيجات. فأن زاوية التعديل، وهي ز ه ط،[٦] مساوية لزاوية ده ج لكونهما متقابلتين. ثم زاوية د ه ج مساوية[٧] لزاوية ط ج ك لكونهما متبادلتين، فأن خطي د ز، ج ك متوازيان. [ج ١٤و] فزاوية التعديل

---

[١] الواقعة: الواقع [ج]

[٢] جوابان: جوابا [ج]

[٣] (١): الأول [ج]، سقطت [هـ]

[٤] (٢): الثاني [ج]

[٥] كتب: الكلمة، سقطت [أ، ب، ج]

[٦] ز ه ط: أ ه ط [ج]

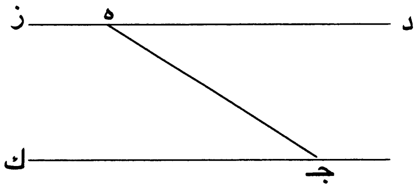
[٧] مساوية: متساوية [ج]

Then the arc which falls between the apogee and (point) *Z* will be one quarter of the cincture of the eccentric. (Also), the position of the sun on the parecliptic with respect to the center of the world will be point *T*. Thus [f. 14v] if we want to measure the arc (extending) from the apogee to (point) *T* along the cincture of the parecliptic, then we must subtract the arc *TK* from one quarter of the parecliptic, and it is not sufficient to subtract (arc) *TZ*, which is the arc (*watar*, sic) of the equation angle.

[11] [f. 15r] I say, there are two responses to this: 1) the object of astronomy is to determine the position of the sun with respect to the center of the world. Its (i.e. the sun's) position with respect to the center of the eccentric is (point) *Z*, while with respect to the center of the world it is (point) *T*. If arc *ZT* is subtracted from the mean (longitude), then (the sun's) position is determined with respect to the center of the world. That which is mentioned in the astronomical tables (*zījāt*) (will in this case) indicate the portion of the arc described on the cincture of the parecliptic (itself).

[12] 2) On the other hand, that which is mentioned in the books of astronomy may indeed refer to that which is determined in the astronomical tables. For the equation angle, namely (angle) *ZHT*, is equal to angle *DHG*, because they are opposite (angles). Angle *DHG* is also equal to angle *TGK*, since they are alternate (angles), and since lines *DZ* and *GK* are parallel. The equation angle is thus

تساوي[1] زاوية ط ج ك.



(شكل ١٦)

[١٣] والزاوية إنما يمكن نقصانها عن قوس من محيط دائرة أو زيادتها عليها إذا وضعت على مركزها، ثم تنقص القوس الموترة لها عن تلك[2] [ف ٢٦٣و] القوس، أو تزاد عليها. فإذا وضعت زاوية التعديل عند مركز العالم على زاوية ط ج ك انطبقت عليها؛ فالقوس الموترة لها من منطقة الممثل ط ك، فهي التي تنقص عن الوسط أو تزاد عليه.

[١٤] /وهاتان صورتا فلك الشمس على أصل التدوير [خ ١٣ظ] والخارج، وصورة زاوية التعديل وقوسه.[3] (شكل ١١، ١٣)

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[1] تساوي: مساوي [ب]

[2] تلك: ذلك [ف]

[3] /وهاتان ... قوسه: العبارة، شرح [ج]

be equal to angle *TGK*.

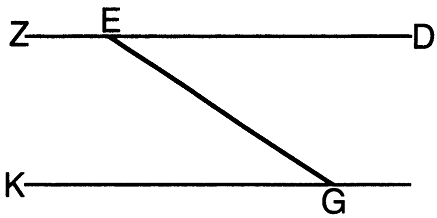


FIGURE 16

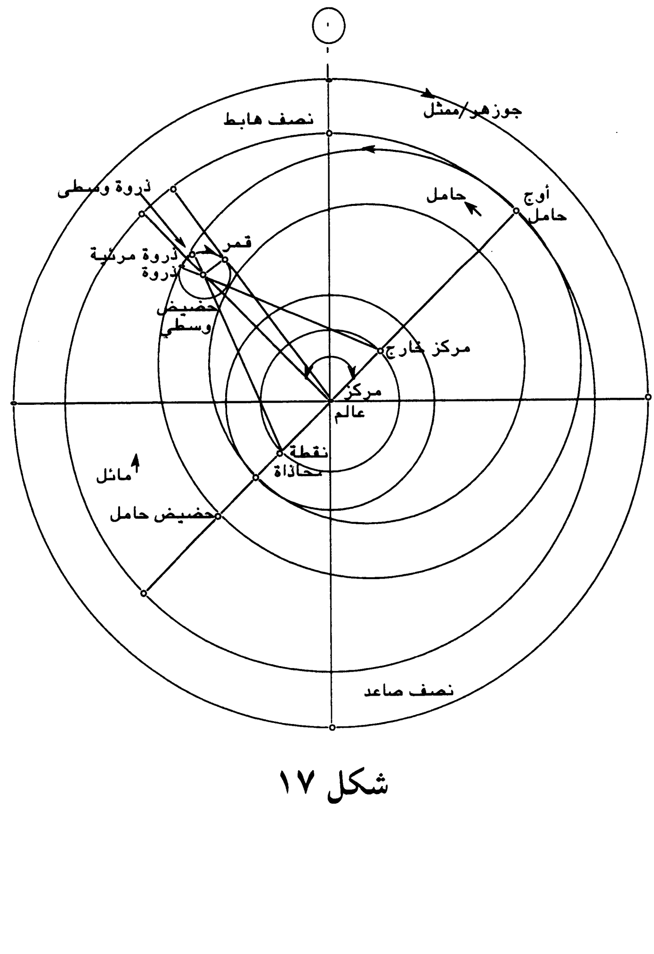
[13] Moreover, an angle can only be subtracted from or added to an arc on the circumference of a circle, if it is placed at the center (of this same circle). The arc subtended by (that angle) can then be subtracted from or added to that (first) arc. Thus if the equation angle is placed at the center of the world, on angle *TGK*, (the two angles) will coincide. Since the arc of the cincture of the parecliptic which is subtended by it (i.e. by angle *TGK*) is (arc) *TK*, this (arc) is therefore the one which is subtracted from or added to the mean longitude.

[14] The following two diagrams are those of the orb of the sun according to the epicyclic and the eccentric hypotheses, in addition to the diagram of the angle and arc of the anomaly. (Figures 11, 13)

[١] [أ ١٥ظ، ف ٢٦٣و، هـ ١٠و] فصل: في أفلاك القمر.

[٢] وجد مداره منصفا لمدار الشمس، [ب ١٩٦ظ] أي منطقة البروج، على نقطتين منتقلتين إلى خلاف التوالي، كل يوم ثلاث دقائق، بأن وجد انتقال محل الكسوفات كذلك، [ج ١٤ظ] وكذا غاية العرض.

[٣] فلا بد من فلك يتحرك كذا، وهو الممثل، [ف ٢٦٣ظ] ويسمى فلك الجوزهر، لأنه، وهو نقطة التقاطع، يتحرك به. فالتي إذا جاز الكوكب صار شماليا عن منطقة الممثل رأس، ومقابله ذنب.



شكل ١٧

[1] [f. 15v] Chapter [5]: On the Orbs of the Moon.

[2] Its (i.e. the moon's) orb was found to bisect the orb of the sun, that is the zodiacal belt, at two points which move three minutes per day in the direction opposite to the sequence of the signs, (and that was determined) by noting that the displacement of the locations of solar eclipses has the same (value), and so is (the case with the point) of maximum latitude.

[3] An orb which moves in the (above) manner is therefore required, namely the parecliptic, which is (also) called the orb of the nodes (*jawzahr*) because (the parecliptic orb) is moved with the movement of the nodes, (the latter) being the intersection (of the moon's orb and the parecliptic). The (node) at which the planet (moon) crosses to the north of the cincture (*minṭaqa*) of the parecliptic, is the head, while the one diametrically opposite to it is the tail.

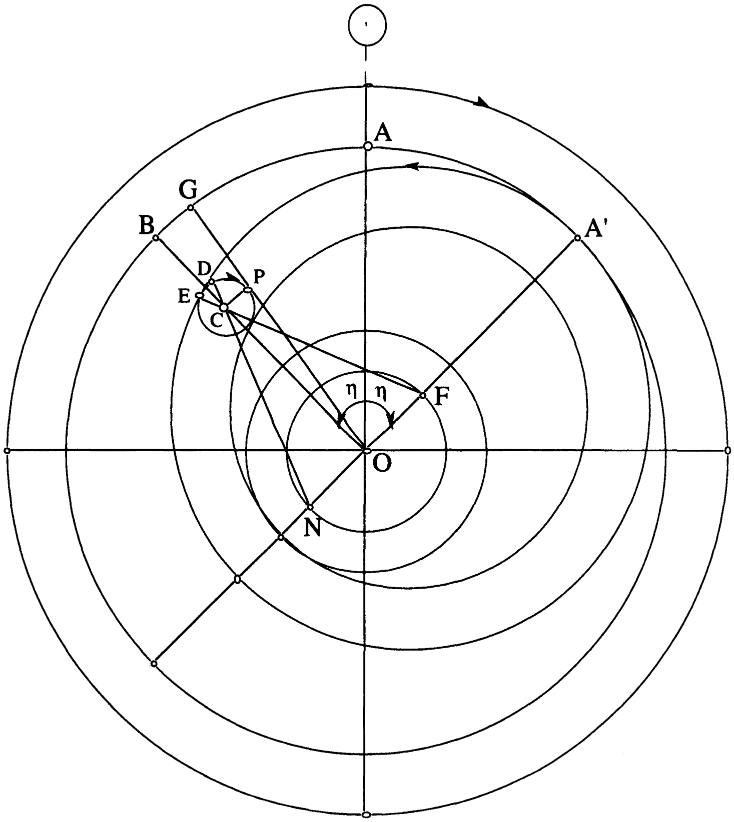


FIGURE 17

[٤] ثم في جوفه فلك يسمى مائلا لميل منطقته عن منطقة الممثل. وهو عرضه شمالا وجنوبا غايته كل خمس درجات.[١] يتحرك كالأول يا ط يح. ومركزهما مركز العالم.

[٥] ثم في ثخن المائل خارج مركز. في ثخنه [أ ١٦و] تدوير، يكون القمر مركوزا فيه على الرسم المذكور. [خ ١٤و] لأنهم وجدوا القمر في الأوج في كل اجتماع و استقبال، بأن وجدوا غاية بطئه وبعده عن الأرض فيهما؛ وفي الحضيض في تربيعي[٢] الشمس، [ب ١٩٧و، ج ١٥و] بأن وجدوا غاية سرعته وقربه من الأرض [ف ٢٦٤و] فيهما. ثم مع ذلك احتيج الى نقصان تعديل[٣] أو زيادته بحيث لا يمكن ذلك مع ما ذكر إلا بالتدوير.

[٦] [أ ١٦ظ، خ ١٤ظ، هـ ١٠ظ] فتكون الشمس[٤] مع مركز التدوير في الأوج أو متوسطة بينهما. فيكون الأوج متحركا إلى خلاف التوالي بالمائل يا يب يح، والشمس إلى التوالي ح نط ح، فمبلغها يب يا كو،[٥] نصف[٦] حركة مركز التدوير [ف ٢٦٤ظ] بخارج المركز من

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[١] كل خمس درجات: كذا في جميع النسخ، بمعنى «كل الدرجات الخمس»

[٢] تربيعي: تربيع [ج]

[٣] تعديل: بعد [أ]

[٤] فتكون الشمس: العبارة، في الهامش [ج]

[٥] كو: يج [ج]

[٦] نصف: نصفه [ج]

[4] The next orb inside (the orb of the nodes) is called the inclined orb because its cincture has an inclination with respect to the cincture of the parecliptic. The maximum value of the northern and southern latitudes is five degrees. It (i.e. the inclined orb) moves (in the same direction) as the first (orb of the nodes), but at 11;9,18 (degrees per day). The center of the (above) two orbs is the center of the world.

[5] Next, there is an eccentric (orb embedded) in the thickness of the inclined (orb). The epicycle is (embedded) in the latter's (i.e. the eccentric's) thickness, [f. 16r] such that the moon is fixed on it in the aforementioned manner. (The eccentric was posited) because the moon was found to be at the apogee during every conjunction and opposition, since the extreme limits of its (i.e. the moon's) slowness and its distance from the earth were found at those two (instances); (and because the moon was also found to be) at perigee at the two quadratures from the sun, since the extreme limits of its speed and closeness to the earth were also found at those two (instances). Moreover, an addition or subtraction of an equation is also required, and this (addition or subtraction), together with that which is mentioned above, are not possible except through an epicycle.

[6] [f. 16v] (In this configuration) the sun either falls, together with the center of the epicycle, at the apogee, or falls midway between the two (i.e. the center of the epicycle and the apogee). The apogee moves 11;12,18 (degrees per day) by the inclined (orb), in the direction opposite to the sequence of the signs. The sun moves 0;59,8 (degrees per day) in the direction of the sequence of the signs. The resultant of the two is 12;11,26 (degrees per day), half the motion of the center of the epicycle due to the eccentric, away from

الأوج، و هي كد كب نب. [ج ١٥ظ] فالوسط، وهو حركة مركز التدوير من النقطة المفروضة من فلك البروج يجـ ي لد.[١]

[٧] وقد أثبتوا التدوير بأن وجدوا القمر [ب ١٩٧ظ] مختلفاً في البطء والسرعة في[٢] أجزاء لا بأعيانها من فلك البروج، عائدا كل اختلاف لا إلى مثله، بل إلى ما يشبهه، بعد تمام الدور بزمان [خ ١٥و] قليل.

[٨] [أ ١٧و، ب ١٩٨و، ج ١٦و، خ ١٥ظ، ف ٢٦٥و، هـ ١١و] ثم التدوير أسفله إلى التوالي وأعلاه إلى خلافه، إذ في الكسوف كلما كان جرم القمر أصغر كان أبطأ، وكلما كان[٣] أعظم كان أسرع. [أ ١٧ظ، ف ٢٦٥ظ] وكذا في الاستقبال والتربيعين،[٤] [ج ١٦ظ، خ ١٦و] فهو في البطء قد يقرب من[٥] الأرض وقد يبعد، وكذا في السرعة. [أ ١٩و، ب ١٩٨ظ] وأيضا زمان سرعته أقل من زمان بطئه. [هـ ١١ظ] وحركته كل يوم يجـ د. [ج ١٧و، ف ٢٦٦و، خ ١٦ظ]

[٩] ثم له اختلافات: (١)[٦] إن[٧] أخرج خطان من مركز العالم إلى

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[١] لد: كد [ج]

[٢] في: إلى [ب]

[٣] كان: الكلمة، في الهامش [ج]

[٤] التربيعين: التربيعي [خ]

[٥] من: إلى [ج]

[٦] (١): ١ [أ، ب، ج، هـ، خ]، أحدها [ف]

[٧] إن: إذا [ب]

the apogee, namely 24;22,52. Thus, the mean (arc), which is the motion of the center of the epicycle away from the fixed point on the ecliptic orb, is 13;10,34.

[7] The (existence of the) epicycle was established by noting that the slowness and fastness of the moon differed in different parts of the ecliptic orb, such that each variation (in the value of the speed) does not occur at the same (point of the preceding variation), but returns to a similar value a short while after the completion of a full revolution.

[8] [f. 17r] Moreover, the lower part of the epicycle moves in the direction of the sequence of the signs, whereas its upper part moves in the opposite (direction), because, during solar eclipses, the smaller the size of the moon is, the slower it would be, and the bigger it is, the faster it would be. [f. 17v] The same (applies) at conjunctions and at the two quadratures; thus, during (the period of) slow motion it (i.e. the moon) may approach the earth or draw away from it, and similarly during (the period of) fast motion. [f. 19r] Moreover, the period of its (i.e. the moon's) fast (motion) is shorter than the period of its slow (motion). Furthermore, its (i.e. the epicycle's) daily motion is 13;4°.

[9] Next, it (i.e. the moon) has variations; (1) if two lines are issued from the center of the world to

منطقة المائل، يمر أحدهما على مركز التدوير والآخر على جرم القمر، فإن كان القمر على الذروة أو الحضيض يتحدان، وإلا يختلفان. فالقوس من المنطقة بينهما هو التعديل الثاني [١] في الزيجات. وغايته قوس جيبها نصف قطر التدوير. وذا في الأوج ه يه، [٢] على إن نصف قطر المائل ستون. وقوسه ه. فينقص من الوسط إن كان القمر هابطا من الذروة، ويزاد عليه إن كان صاعدا، لأن أعلى التدوير يتحرك إلى خلاف التوالي.

[١٠] [أ ١٩ظ، ب ١٩٩و، ف ٢٦٦ظ] (٢) [٣] إن الاختلاف في الأوج كذا، ففي غيره كم يكون؟ وقد وجد نصف قطر التدوير في الحضيض [خ ١٧و] زائدا [٤] على ما في الأوج بقدر ب م. فوضع جدول لحركة [٥] التدوير، وهو أن قوس التدوير التي تعديلها في الأوج ه اختلافها ب م . فالقوس التي تعديلها أقل من ه كم يكون اختلافها في الحضيض. مثلا ، القوس التي تعديلها ثمة جـ ، وهو ثلاثة أخماس ه، اختلافها هنا ثلاثة أخماس ب م ، وهي أ لو.

[١١] ثم أردنا أن نعرف هذا فيما فوق الحضيض. فاحتجنا إلى

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[١] الثاني: الكلمة، غير واضحة [أ]

[٢] ه يه: الكلمة، غير واضحة [أ]

[٣] (٢): ٢ [أ، ب، ج، هـ، خ]، الثاني [ف]

[٤] زائدا: +«لقوله من مركز العالم»، تحت السطر [أ]

[٥] جدول لحركة: +«جدول الاختلاف»، تحت السطر [أ]

the cincture of the inclined (orb), such that one of them passes through the center of the epicycle and the other through the body of the moon, then if the moon is at the apogee or perigee of its epicycle they (i.e. the two lines) coincide, otherwise, they differ. The arc of the cincture (of the inclined orb) is thus the second equation in the astronomical tables. Its maximum value is an arc whose sine is (equal to) the radius of the epicycle. At the apogee (of the eccentric) this (radius) is (equal to) 5;15 (parts), assuming that the radius of the inclined (orb) is (equal to) sixty (parts). Its arc is then (equal to) 5 (degrees). It is thus subtracted from the mean (longitude) if the moon is descending from the epicyclic apogee, and added to it when it is ascending, because the upper part of the epicycle moves in the direction opposite to the sequence of the signs.

[10] [f. 19v] (2) Having (found) the variation at the apogee to have a certain value, then how much would it be at some other (location)? The (apparent) radius of the epicycle at perigee was found to be greater than at apogee by a value of 2;40 parts. A table for the motion of the epicycle was then set up, so that it has a variation of 2;40 when the arc of the epicycle has an equation at apogee of 5 (degrees). What would the corresponding variation be if the equation were less than 5 (degrees)? For example, the arc which has an equation of 3 (degrees) there (i.e. at the apogee), that being three fifths of 5 (degrees), would have a variation of three fifths of 2;40 (parts) here (i.e. at the perigee), which is 1;36 (parts).

[11] Next, if we want to find this (value of the variation at any point) above the perigee, then we need

جدول[1] آخر، وهوأنا فرضنا أن الحضيض أقرب إلى مركز العالم من الأوج بهذا: ك ح.[2] فنقول: إن كان الاختلاف في هذا البعد درجة، ففي أجزاء خارج المركز التي بعدها أقل يكون بهذه النسبة. ففي الجزء الذي هو أقرب إلى مركز العالم بهذا: ي ح،[3] يكون اختلافه نصف اختلاف الحضيض. فهو إذا كان أ لو يضرب في ل دقيقة [ج ١٧ظ] ليحصل المطلوب، فيزاد على التعديل الثاني، ثم ينقص أو يزاد كما عرفت.

[١٢] [أ ٢٠ظ، ب ١٩٩ظ، ج ١٨و، ف ٢٦٧ظ، خ ١٨و] (٣)[4] اختلاف[ب ٢٠٠و] المحاذاة،[5] وهو التعديل الأول في الزيجات. وهو أنه إذا أخذ الوسط، وهو قوس من منطقة المائل بين أول الحمل وطرف الخط المنتهي إليها من مركز العالم، مارا بمركز التدوير، ثم أخذت الخاصة من نقطة على أعلى التدوير يمر عليها ذلك الخط إلى مركز القمر، وأخذ بأزائه [ج ١٨ظ] التعديل الثاني، فينقص أو يزاد على الرسم، يتعين موضع القمر إذا كان مركز التدوير في الأوج أو الحضيض، أما في غيرهما فلا. بل إنما يتعين إذا كان التدوير هابطا من الأوج بأن يزاد

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[1] جدول: +«جدول الحضيض»، تحت السطر [أ]

[2] ك ،: ك مه [ب]

[3] ي ح: ي ه [ب]

[4] (٣): ٣ [أ، ب، ج، هـ، خ]، الثالث [ف]

[5] المحاذاة: المحاذلت [ج]

another table: for this, once we assume that the perigee is closer to the center of the world than the apogee by (a value) of 20;0 (parts), we say that, for a variation of one degree at this distance (i.e. between the apogee and the perigee), the part of the eccentric whose distance is less (than 20;0) will have a corresponding value. Thus, when the part (of the eccentric) is 10;0 (parts) closer to the center of the world, one degree will have one half the variation it has at the perigee. So if this (latter variation) is (equal to) 1;36, it should be multiplied by 30 minutes, in order to obtain the required (value). (The product) is then subtracted or added to the second equation as already explained.

[12] [f. 20v] (3) The (third) variation due to the prosneusis (point) is the first equation in the astronomical tables. It is (found in the following manner): measure the mean longitude on the cincture of the inclined (orb), that being the arc which falls between the beginning of Aries and the extremity of the line issued from the center of the earth, passing through the center of the epicycle, and ending at (this cincture). The (mean) anomaly is measured between a point on the upper part of the epicycle through which the (above) line passes and the moon. The second equation is (the tabular entry found) next to it (i.e. to the value of the measured anomaly). That is either subtracted or added accordingly. The position of the moon is (already) determined, if the center of the epicycle is at the apogee or the perigee; at any other (position) it is not. Rather, in the case when the epicycle is descending from the apogee, it (i.e. the position of the moon) is determined by adding

شيء، وهو التعديل الأول على الخاصة، غايته عند طرف خط قائم[١] على خط[٢] الأوج والحضيض، مار[٣] على نقطة [أ ٢١و] المحاذاة، أي نقطة على خط الأوج والحضيض،[٤] بعدها عن[٥] مركز [خ ١٨ظ] العالم كبعده عن مركزالخارج، مقاطرة له. [ف ٢٦٨و] كل من البعدين ي يط بتقدير مر، وغاية[٦] التعديل بحسب هذا.

[١٣] وإذا كان التدوير صاعدا، فبأن ينقص في كل جزء مثل مايزاد في الطرف الآخر في جزء بعده عن الأوج كبعده منه.

[١٤] [هـ ١٢و] فدل [ب ٢٠٠ظ] على أن الذروة الوسطى، وهي مبدأ الخاصة، أخذت في الحركة إلى خلاف التوالي، والحضيض إلى التوالي، عند كونه على طرف ذلك الخط صاعدا، [أ ٢١ظ، ج ١٩و، خ ١٩و، ف ٢٦٨ظ] حتى انطبق عند الأوج على الذروة المرئية والحضيض، أي المحاذيين لمركز العالم. فإذا فارقه مال الذروة الوسطى عن المرئية إلى خلاف التوالي، والحضيضان بالخلاف. [ج ١٩ظ، خ ١٩ظ] حتى انطبق

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[١] قائم: +«الحق أن الغاية تحته بمقدار يا لد على ما وضع في المجسطي الغاية في قيد»، تحت السطر [أ]

[٢] خط: الكلمة، سقطت [ج]

[٣] مار على نقطة: العبارة، سقطت [ج]

[٤] الأوج والحضيض: العبارة، سقطت [ج]

[٥] عن: في، ثم صححت فوقه [ج]

[٦] غاية: +«والحق أن الغاية أكثر من مقتضى هذا البرهان»، في الهامش [أ]

something (to the anomaly,) namely the first equation. Its maximum value (i.e. that of the first equation) is at the end of a line which is perpendicular to the apsidal line, and which passes through the prosneusis [f. 21r] point, that is a point on the apsidal line whose distance from the center of the world is equal to the (latter's) distance from the center of the eccentric, and is diametrically opposite to it. Each of the two distances is (equal to) 10;19 (parts), according to a previously mentioned consideration, and the maximum value of the (first) equation is dependent on this (distance).

[13] If, (on the other hand), the epicycle is ascending (from perigee), then (the position of the moon is determined) by subtracting, at every part, the same (value) that was added in the other (descending) side, at parts whose distances away from the apogee are equal.

[14] (The above) indicates that the mean epicyclic apogee, which is the starting point of the anomalistic (motion), begins to move in the direction opposite to the sequence of the signs, while the perigee moves in the direction of the sequence of the signs, when the center of the epicycle is at that end of the line (which is perpendicular to the apsidal line of the eccentric at the prosneusis point) where the epicycle would be ascending (from the perigee of the eccentric). [f. 21v] Then (this line) coincides with the visible epicyclic apogee and perigee, when (the center of the epicycle) is at the apogee in line with the center of the world. If, however, (the center of the epicycle) departs (from the apogee), then the mean epicyclic apogee slants away from the visible (apogee), in the direction opposite to the sequence of the signs, and conversely for the two perigees. The two diameters also coincide

[ف ٢٦٩و] القطران عند الحضيض. [ب ٢٠١و] ثم فارقا، ومال الذروة الوسطى عن المرئية إلى التوالي، والحضيضان بالخلاف، حتى يصل إلى طرف الخط [أ ٢٢و] المذكور صاعدا. فتعين موضع[1] القمر، بزيادة[2] التعديل [هـ ١٢ظ] ونقصانه على وجه توجبه المحاذاة، دل عليها.

[١٥] [أ ٢٢ظ، ب ٢٠١ظ، ج ٢٠و، خ ٢٠ظ، ف ٢٧٠و، هـ ١٣و] فأهل هذا الفن تحيروا في أنه كيف [ج ٢٠ظ] يتصور تشابه الحركة بالنسبة إلى مركز العالم، الدال عليه غنى الوسط [أ ٢٣و] عن التعديل الأول، مع[3] تساوي القرب والبعد بالنسبة إلى مركز الخارج، الدال عليه رؤية نصف قطر التدوير على ما ذكر، [ب ٢٠٢و] /مع محاذاة القطر نقطة المحاذاة.[4]

[١٦] فصاحب التذكرة لم يغادر صغيرة ولا كبيرة إلا أحصاها، /ولم يجد ما عملوا حاضرا،[5] [خ ٢١و، ف ٢٧٠ظ] حيث أثبت ثلاث كرات للتشابه، ثم قال: هذا لا يطابق الأصل الذي عملوا عليه مطابقة تامة، لوقوع التفاوت بسدس درجة، وثلاثا أخر للمحاذاة. فلزم أن تكون غاية الاختلاف في منتصف الأوج والحضيض، والواقع بخلافه.

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[1] موضع: موضوع، ثم صححت [ب]

[2] بزيادة: الكلمة، تكررت [أ]

[3] مع: ومع [ج]

[4] /مع ... المحاذاة: العبارة، شرح [ب]

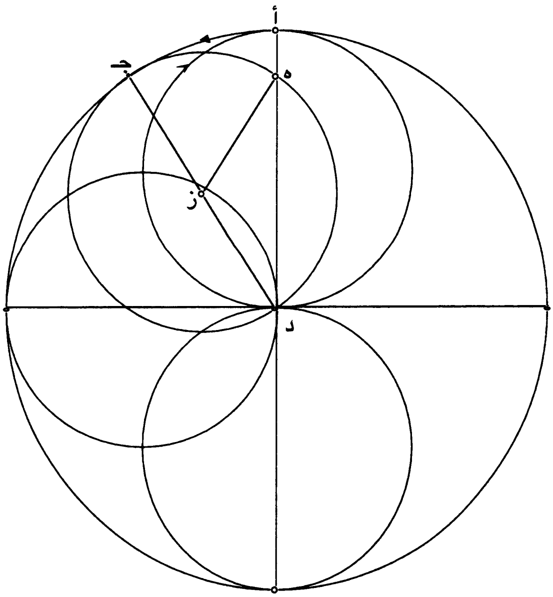
[5] /ولم ... حاضرا: العبارة، مقتبسة من القرآن (كهف، ١٨)

at perigee, and then depart (away from each other). The mean epicyclic apogee thus slants away from the apparent (one), and conversely for the two perigees, until it (i.e. the epicycle center) reaches the extremity of the above mentioned line [f. 22r] during the ascent (of the epicycle). The determination of the position of the moon, by adding or subtracting the equation in the manner entailed by the prosneusis point, therefore, proves (the epicycle's existence).

[15] [f. 22v] The practitioners of this science wondered about the manner in which one could envision: (1) uniform motion around the center of the world, as indicated by the mean longitude not needing to be corrected by [f. 23r] the first equation, while at the same time (2) the closeness and remoteness with respect to the center of the eccentric remain equal, that being indicated by the observable magnitude of the epicyclic radius, which was mentioned before, and (3) the alignment of the epicyclic diameter with the prosneusis point.

[16] The author of the *Tadhkira* did not fail to account for any major or minor (detail), and yet he did not find that which was produced (by his predecessors) as satisfactory. He thus posits (in the *Tadhkira*) three spheres for the uniform (motion), and three more (spheres) for the prosneusis. Then he says: this does not fully correspond to the principle by which they (i.e. the ancients) have worked, because of the occurrence of a discrepancy of one sixth of a degree. (The principle of Ṭūsī) requires that the maximum value of the variation occur at the midpoint between the apogee and the perigee, whereas in reality it is not so.

[١٧] ومع هذا يذكر طريقة، وهي مبنية على مقدمة: وهي أنه إذا كانت دائرة كبيرة مركزها[١] د، وقطرها أب، وفي سطحها صغيرة مركزها ز، وقطرها جـ د، وهو نصف أ ب. ونقطة جـ تماس أ، وحركتها ضعف الكبيرة في خلاف جهتها. وعلى محيطها نقطة ه، وفرضناها أولا مع أ، فتحركت الكبيرة من أ إلى جانب اليسار مقدار قوس أجـ، والصغيرة إلى خلافه، فقطعت جـ ه، فقوس أ جـ شبيهة[٢] لنصف جـ ه. [أ ٢٣ظ، ج ٢١و]



شكل ٢٦

[١] مركزها: مركزه [ب]
[٢] شبيهة: +مركزها [هـ]

[17] He (i.e. the author of the *Tadhkira*), nonetheless, mentions a method, which is based on a lemma (figure 10): (consider) that a large circle whose center is *D*, and whose diameter is *AB*, has in its plane a small circle whose center is *Z*, and whose diameter is *GD*, which is half *AB*. Point *G* is contiguous with point *A*, and its motion (i.e. that of the small circle) is twice that of the large one, and in the opposite direction. (Consider) a point *E* on its circumference (i.e. that of the small circle), and let us assume that it (i.e. point *E*) coincides initially with *A*. (Now) if the large (circle) moves to the left a distance equal to arc *AG*, and if the small one (moves) in the opposite direction through *GE*, then arc *AG* is equal to one half arc *GE*.

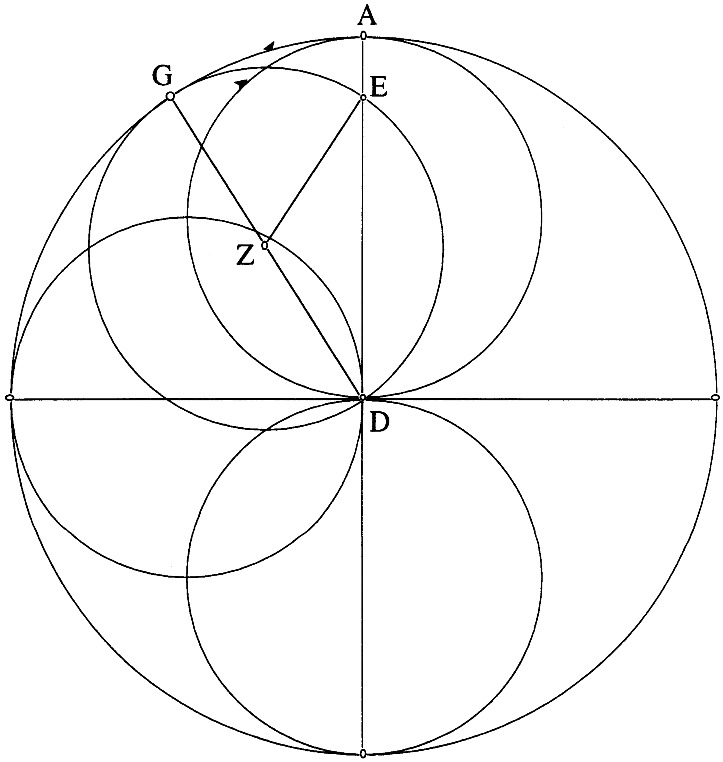


FIGURE 26

[١٨] فنصل خط د ه وخط ز ه، فزاوية جـ ز ه ضعف زاوية جـ د أ، [هـ ١٣ظ] وهي أيضا ضعف زاوية جـ د ه لكونها خارجة عن مثلث ه ز د، [خ ٢١ظ] ومســـــاوية لداخلتي [ب ٢٠٢ظ] ز ه د، ز د ه[١] المتساويتين لتساوي ساقي [ف ٢٧١و] زه، زد. فزاويتا جـ د ه،[٢] جـ د أ متساويتان وخط ده منطبق على دأ. فنقطة ه على قطر أ ب، غير زائلة عنه.

[١٩] وكذا في جميع أوضاع تمكن عمل المثلث. وإذا لم يمكن، وذلك عند حركة الكبيرة ربع الدور أو ثلاثة أرباعه، والصغيرة ضعف ذلك، فحينئذ تقع ه على د؛ [أ ٢٤و، ج٢١ظ، ف٢٧١ظ] أو عند حركتها نصف الدور، والصغيرة الدور، فنقطة ه على جـ عند نقطة ب.

[٢٠] [خ ٢٢و] إذا عرفت هذا تفرض حاملا مركزه مركز العالم. في ثخنه الكبيرة، يتم دورهما[٣] معا. في ثخنها صغيرة، يماس محدباهما على نقطة، وحركتها ضعف تلك في خلاف جهتها. [ب ٢٠٣و] في ثخنها [هـ ١٤و] حافظة لوضع التدوير كما مر، وحركتها كالكبيرة وفي جهتها. وفي جوفها التدوير.

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[١] زده: +«جـ د أ»، فوق السطر [أ]، الكلمة، سقطت [ب]

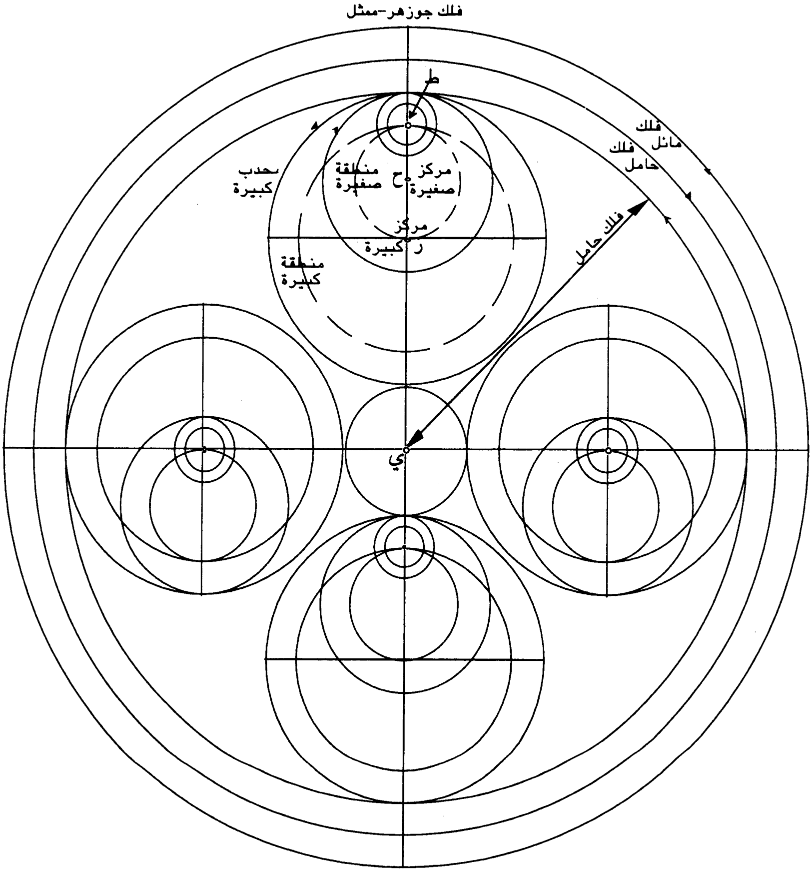
[٢] جـ د ه: الكلمة، سقطت [ج]

[٣] دورهما: دورها [ج]

[18] [f. 23v] If we join lines *DE* and *ZE*, then angle *GZE* is twice angle *GDA*. (The former angle) is also twice angle *GDE* because it is exterior to triangle *EZD*, and it is equal to the two interior (angles) *ZED* and *ZDE*, which are (in turn) equal because of the equality of the two sides *ZE*, *ZD*. The two angles *GDE*, *GDA* are thus equal, and line *DE* coincides with line *DA*. Therefore, point *E* falls on diameter *AB*, without deviating from it.

[19] The same applies at all the positions where a triangle (*EZD*) can be constructed. If this (construction) is not possible, which is (the case) when the large (circle) moves either a quarter or three quarters of a revolution, and the small one (moves) twice that amount, then *E* falls on *D*; [f. 24r] or, (alternatively), when (the large circle) moves one half of a revolution, and the small (circle moves) one revolution, then *E* and *G* (coincide) at point *B*.

[20] Once this is known, consider a deferent whose center is the center of the world. The large (circle) is (embedded) in its (i.e. the deferent's) thickness, such that they complete a full revolution together. A small (circle) is (embedded) in its thickness (i.e. that of the large circle), such that their convex surfaces are tangent at a point, and the (former's) motion is twice that (of the latter) and in the opposite direction. (A circle which) retains the position of the epicycle as mentioned above is (embedded) in the thickness (of the small circle), such that its motion is similar to that of the large (circle) and in its direction. (Finally), the epicycle falls inside this (last circle).



شكل ٢٧

[٢١] ويجب أن يكون قطر محدب الصغيرة زائدا على نصف قطر محدب الكبيرة بقدر نصف قطر التدوير وثخن الحافظة. فالدائرة التي هي مدار مركز التدوير بحركة الكبيرة، لولا حركة الصغيرة، (هي)[١] منطقة

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[١] (هي): الكلمة، أضيفت لاستقامة المعنى

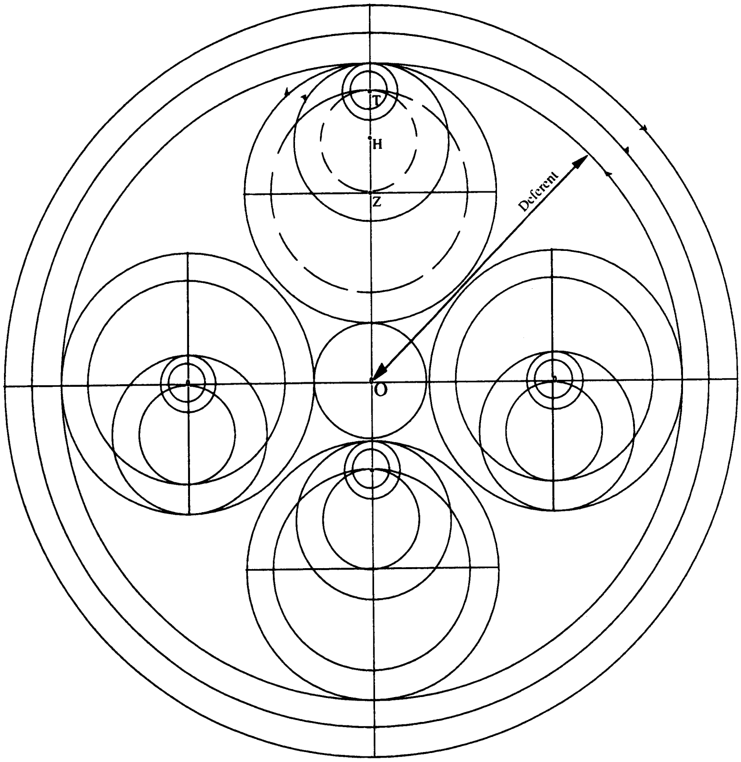

FIGURE 27

[21] The diameter of the convex surface of the small (circle) should be greater than the radius of the convex surface of the large (circle) by the amount of the radius of the epicycle plus the thickness of the retainer (circle). Thus the circle which is

الكبيرة؛ وبحركة الصغيرة، لولا حركة الكبيرة، (هي) [١] منطقة الصغيرة. وقطر هذه بقدر ما بين المركزين على تقدير الخارج. وقطر الأولى ضعف ذلك، وهو مقدار نزول المركز وصعوده. فبهذا الطريق تكون الحركة متشابهة بحسب مركز العالم، مع القرب والبعد.

[٢٢] [أ ٢٥ظ، ب ٢٠٣ظ، ج ٢٣و، خ ٢٣ظ، ف ٢٧٢ظ، هـ ١٤ظ] وأما [٢] المحاذاة، فيجب لها ثلاث كرات: الأولى قطبها محاذ لمنطقة التدوير، بحيث تحاذيه الذروة عند عدم الاختلاف. والثانية في جوفها، بعد قطبها عن قطبها بقدر نصف غاية الاختلاف. والثالثة في [أ ٢٦و] جوفها حافظة لوضع التدوير، وقطبها محاذ للأولى.

[٢٣] وفرضنا التدوير عند غاية الاختلاف صاعدا، فالبعد بين قطب الأولى [٣] والذروة بقدر [٤] غاية الاختلاف، والذروة شرقية عن القطب. وقطب الثانية حينئذ محاذ لمنطقة التدوير، شرقي [٥] عن قطب الأولى، متوسط [٦] بينه وبين الذروة.

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[١] (هي): الكلمة، أضيفت لاستقامة المعنى

[٢] قبل البدء بهذه الفقرة ورد رسم أفلاك القمر حسب هيئة بطليموس [أ ٢٥و]، وحسب هيئة الطوسى [أ ٢٥ظ]، إضافة إلى فقرة طويلة في هامش [أ]. وقد سقطت هذه الفقرة في [ب]، وكتبت كجزء من الشرح في [ج]

[٣] الأولى: الأول [ج]

[٤] بقدر: +«تر»، بعدها، ثم شطبت [أ]

[٥] شرقي: شئ في [هـ]

[٦] متوسط: متوسطه [ب]

the path of the center of the epicycle as it is moved by the large circle (above), without considering the motion of the small circle, is the cincture of the large (circle); and (the circle drawn by the motion) of the small (circle), without considering the motion of the large circle, is the cincture of the small (circle). Moreover, the diameter (of the cincture of the small circle) is equal to the distance between the two centers assuming the eccentric (hypothesis). (On the other hand), the diameter of the first (i.e. the cincture of the large circle) is twice as much, which is the amount of the descent and ascent of the (epicycle) center. Thus, by this method, the motion will be uniform relative to the center of the world, in spite of the closeness and the remoteness (of the moon).

[22] [f. 25v] As for the prosneusis, it requires three spheres: the pole of the first is aligned with the cincture of the epicycle, such that the epicyclic apogee is aligned with it when there is no variation. The second is inside it (i.e. the first sphere), such that the distance between the pole (of the first) from the pole of the second is equal to one half of the maximum variation. The third (sphere) is [f. 26r] inside (the second sphere); it retains the position of the epicycle, and its pole is aligned with the first.

[23] If we assume the epicycle to be ascending from the (point) of maximum variation, then the distance between the pole of the first (sphere) and the epicyclic apogee is equal to the maximum limit of the variation, and the epicyclic apogee is east of the pole. The pole of the second (sphere) will then be aligned with the cincture of the epicycle, (and it will fall) east of the pole of the first sphere, halfway between it and the epicyclic apogee.

[٢٤] فلولا[١] الثانية [ب ٢٠٤و] تتحرك الذروة بحركة الأولى [ف ٢٧٣ظ، هـ ١٥و] على دائرة قطرها ضعف غاية الاختلاف، فهي الكبيرة. ولولا الأولى تتحرك بالثانية نصف ذلك. فالصغيرة هي هذا المدار.

[٢٥] ففرضنا الأولى متحركة كالحامل، والثانية ضعفها إلى خلاف جهتها، والثالثة كالأولى في جهتها. فتأخذ الذروة في الحركة إلى المغرب حتى تحاذي[٢] الذروة قطب الأولى في الأوج. ثم تفارقه، وتهبط حتى تنتهي إلى غاية الاختلاف. فتأخذ الذروة في الحركة [ب ٢٠٤ظ] إلى المشرق حتى تحاذي الذروة قطب الكبيرة في الحضيض. فتفارقه وتصعد، فتصل إلى الحالة الأولى.

[٢٦] [ج ٢٣ظ، خ ٢٤و] وصاحب التحفة زاد[٣] تدويرا. وتقريره أن يثبت خارج مركز خروج مركزه نصف ما وجدوه،[٤] وهو ه ي، في ثخنه تدوير، يتحرك أعلاه إلى التوالي. بمقدار الخارج، [خ ٢٤ظ] أي البعد المضاعف. ثم في ثخنه تدوير فيه القمر، بعد ما بين مركزيهما ه ي، بحيث يماس محدباهما على نقطة. حركته مثل الخارج والخاصة.

[٢٧] [أ ٢٦ظ، ف ٢٧٤و] فلنفرض الأوج أ، ومركز الخارج ب،

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[١] فلولا: الكلمة، سقطت [هـ]

[٢] تحاذي: يبتحاذى [ب]

[٣] زاد: +«لأجل تشابه الحركة»، بعدها [ج]

[٤] وجدوه: +«ي ك»، تحت السطر [أ]

[24] Thus, were it not for the motion of the second (sphere), the epicyclic apogee would move by the motion of the first (sphere) along a circle whose diameter is twice the value of the maximum variation, namely the large (circle). (Moreover), were it not for the motion of the first (sphere), it (i.e. the epicyclic apogee) would move by the second (sphere along a circle whose diameter is) half of that (maximum variation). This path is that of the small (circle).

[25] Consider that the first (sphere) moves like the deferent, and that the second (moves) twice (as fast as the first) and in the opposite direction, while the third (moves) like the first and in the same direction. The epicyclic apogee then starts to move towards the west until the epicyclic apogee aligns with the pole of the first (sphere) at the apogee. It (i.e. the epicyclic apogee) then departs from (the apogee), and descends until it reaches the (point of) maximum variation. The epicyclic apogee then starts to move toward the east until the epicyclic apogee aligns with the pole of the large (sphere) at perigee. It (the epicyclic apogee) then departs from (perigee), and ascends until it reaches the first position.

[26] The author of the *Tuḥfa* added an epicycle. It is determined by positing an eccentric whose eccentricity is half of that which is found (for the Ptolemaic model), namely 5;10 (parts), and in whose thickness the epicycle is embedded, such that its upper part moves in the direction of the sequence of the signs. (The diameter of this epicycle is) equal to the amount of the eccentricity (of the Ptolemaic model), that is twice the distance (between the center of the world and the center of the new deferent). The (second) epicycle in which the moon is (carried) is in the thickness (of the first epicycle), and the distance between their centers is 5;10 (parts as well), such that their convex surfaces are tangent at one point. The motion (of the second epicycle) is equal to that of the eccentric and the anomaly.

[27] [f. 26v] Let the apogee be (point) *A*, the center of the eccentric be *B*,

ومركز العالم جـ، ومركز التدوير الأول د، ومركز ذي الكوكب ه.[١] وفرضنا أولا نقطتي د و ه على خط أب. [ج ٢٤و] ثم تحرك الخارج من الأوج، وتحرك التدوير الأول يوما وليلة من الأوج. أخرج خط من ب إلى د ينتهي إلى ز، وهي نقطة أينما وقعت، وخط من جـ إلى ه بهذه الصورة (شكل ٣١). فزاوية أ ب ز كزاوية زده لتساوي الحركتين. [ب ٢٠٥و، خ ٢٥و] فالباقيتان متساويتان، وهما ز ب جـ ، ه د ب. فخطا ب د ، جـ ه متوازيان، لأن خط ب د ينصف على س، ويقام عليه عمود يصل إلى نقطة ع من خط جـ ه، ونضع زاوية ب س ع على زاوية د س ع،[٢] فتقع نقطة ب على د، ونقطة [هـ ١٥ظ] جـ على ه، لأن زاويتي د ب جـ،[٣] ب د ه[٤] متساويتان، وكذا خطا[٥] ب جـ ، ده. فخط ع جـ ينطبق على ع ه. [ف ٢٧٤ظ] فالبعد بين الخطين عند نقطة ب، أي خط يخرج[٦] من نقطة ب عمودا[٧] على خط[٨] ب د ، كالبعد بينهما عند

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[١] ه: الحرف، غير واضح [أ]

[٢] د س ع: د س [ج]، ز س ع [ف]

[٣] د ب جـ: جـ ب د [ج]

[٤] ب د ه: ب ه، ثم أضيفت د فوق السطر [ج]

[٥] خطا: خط [ف]

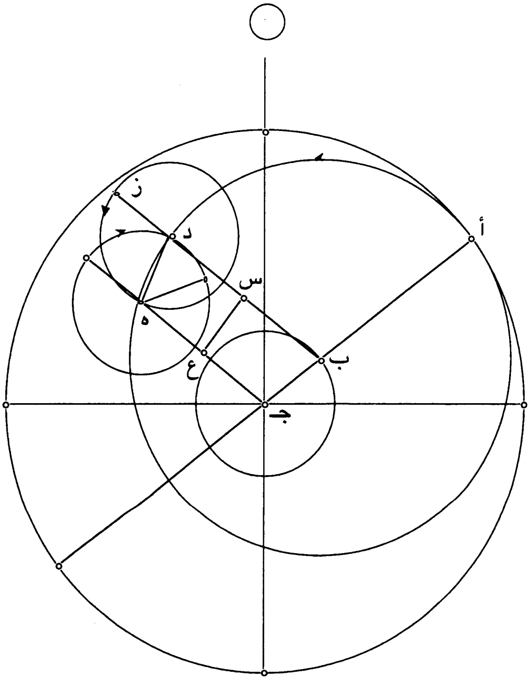
[٦] يخرج: مخرج [ب]

[٧] عمودا: عمود [أ، ب، ج]

[٨] على خط: على [ج]

the center of the world be *G*, the center of the first epicycle be *D*, while the center of that carrying the planet is *E*. Let us first assume points *D* and *E* to be along line *AB*. Then (let) the eccentric move away from the apogee, and let the first epicycle move away from the apogee (as well) by one nychthemeron (a day and a night). Draw a line between (points) *B* and *D* and let it reach *Z*, wherever that point may fall, and (draw) a line between *G* and *E* in the same manner. Angle *ABZ* is equal to angle *ZDE*, since the two motions are equal. The two supplementary (angles) are, therefore, equal, and these are (angles) *ZBG* (and) *EDB*. Lines *BD* (and) *GE* are parallel, since if we bisect line *BD* at (point) *S*, and if we draw the perpendicular to it which intersects line *GE* at (point) *O*, and if we let angles *BSO* and *DSO* coincide, then point *B* coincides with *D*, and point *G* (coincides) with *E*, because angles *DBG* (and) *BDE* are equal, and so are lines *BG* (and) *DE*. Lines *OG* and *OE* thus coincide. (Moreover), the distance between the two lines at point *B*, that is the line which is drawn from point *B* perpendicular to line *BD*, is equal to the distance between them (i.e. the two lines) at

نقطة د، [أ ٢٧و] أي خط خارج من د كما ذكر، ضرورة[١] انطباق ب على د، وانطباق ع جـ على ع ه. فيتحد العمودان؛[٢] فخطا ب د، جـ ه لا يتلاقيان في إحدى الجهتين، إذ لوتلاقيا لتلاقيا[٣] في الأخرى، وذا محال في الخطين المستقيمين. وإذا توازيا، فزاوية أب د مثل زاوية أجـ ه.



شكل ٣١

[١] ضرورة: مر مرة [ج]

[٢] العمودان: +«و إلا لزم تساوي المجرد الكلي أو الاحاطة»، تحت السطر [أ]

[٣] تلاقيا لتلاقيا: يتلاقيا ليتلاقيا [ج]

point *D*, [f. 27r] that is the line which is drawn from (point) *D* as mentioned above. This is a necessary result of the coincidence of points *B* and *D*, and the coincidence of (lines) *OG* and *OE*. The two perpendiculars thus coincide. Therefore, lines *BD* (and) *GE* would never intersect in either one of the two directions, since if they were to intersect in either, then they would intersect in the other, and this is impossible for straight lines. Now if they (i.e. the two lines) are parallel, then angle *ABD* is equal to *AGE*.

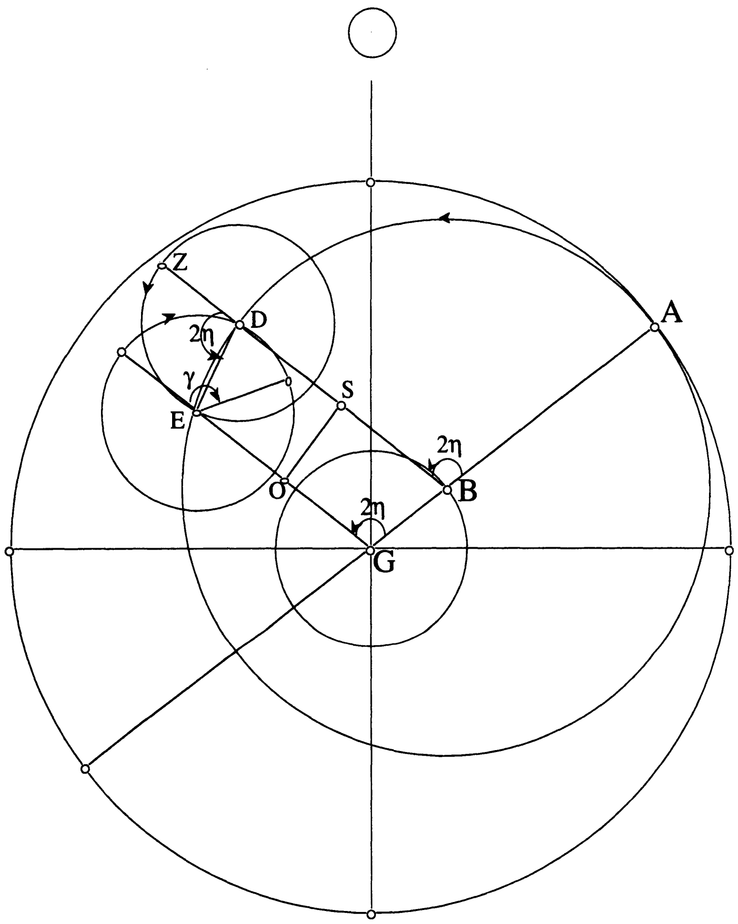


FIGURE 31

[٢٨] [خ ٢٥ظ] ولا يضر اختلاف القسي[1] من المدار[2] البيضي لأن الزوايا عند المركز متساوية، فالقسي متشابهة [ج ٢٤ظ] مع قربها و بعدها.[3] ولا يخل بذلك تحرك مركز الخارج حول مركز العالم، لأن بعده لا يختلف.

[٢٩] فطريق صاحب التحفة حسن يتم به التشابه. وأما المحاذاة، فقد أطنب فيه الكلام، والظاهر أنه لا طائل تحته، إذ مآل[4] كلماته أن حركة الخارج وحدها كافية في اختلاف الذروتين، ولاشك أنه ليس كذلك.

[٣٠] [ف ٢٧٥و] وقد سنح لي طريق حسن، وهو أنه لابد من تدوير صغير في ثخن ذي الخاصة، [ب ٢٠٥ظ] يماس محدباهما على نقطة، نصف قطره نصف جرم القمر مع غاية التعديل الأول،[5] وهو ي يط من أجزاء يكون نصف قطر ذي الخاصة ستون، وهو نب دقيقة تقريبا[6] من أجزاء نصف قطر المائل ستون. [أ ٢٧ظ] يتم دوره مع الخارج، أعلاه موافق لذي الخاصة، وأسفله مخالف له. فذو الخاصة إذا كان في الأوج، والقمر على ذروة الأصغر، فلا تعديل. فإذا فارق الأوج تحرك أعلى

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[1] القسي: الكلمة، سقطت [ب]

[2] المدار: المقدار [ب]

[3] بعدها: +« أي القسي المأخوذة من الدائر المرسومة على مركز العالم باعتبار الأجزاء متساوية، وإن اختلفت بحسب المقدار »، في الهامش [أ]

[4] مآل: الكلمة، سقطت [ج]

[5] الأول: +« ٢ »، فوق السطر [أ]

[6] تقريبا: الكلمة، فوق السطر [أ]

[28] The variation in the arcs of the (resultant) oval path is not (in itself) objectionable, since the angles at the center remain equal, and the (corresponding) arcs are similar despite their closeness and remoteness. Moreover, the motion of the center of the eccentric around the center of the world is also permissible, since its distance (from the center of the world) does not vary.

[29] The method of the author of the *Tuḥfa* is good and fulfills the (principle of) uniformity. As for the prosneusis point, he talks about it at length, but to no avail. The gist of his words is that the motion of the eccentric alone suffices to account for the variation of the two apogees, and there is no doubt that this is not so.

[30] A good method has occurred to me, namely that there should be a small epicycle (embedded) in the thickness of the anomalistic one, such that their convex surfaces are tangent at one point. The radius (of the small epicycle) should be (equal to) half the body of the moon plus the maximum value of the first equation, which is 10;19 (parts) of the same units that make the radius of the anomalistic (epicycle) sixty units, and about 52 minutes of the same units that make the radius of the inclined orb sixty units. [f. 27v] The rotation (of the epicycle) is completed together with the eccentric, such that its upper part (moves) in the direction of the anomalistic (epicycle), whereas its lower part is opposite to it. Thus if the anomalistic (epicycle) is at the apogee, while the moon is at the epicyclic apogee of the smaller (epicycle), then there is no equation. If, however, it departs from the apogee, then the upper part of the smaller (epicycle) moves

الأصغر على وفق ذي الخاصة، فيرى مجموع الحركتين حتى يبلغ الغاية، وهي قريب تثليث الأوج، لأن غاية التعديل في التدوير الأصغر تكون قريبا من هذا الحد. ثم يقل إلى أن يبلغ حضيض الخارج. فيكون القمر[١] في حضيض الأصغر، فلا تعديل. ثم فارقه، يصير [خ ٢٦و] التعديل ناقصا، لأن حركة الخاصة تكون أبطأ، لأن حضيض الأصغر يتحرك بخلافها حتى يبلغ الغاية.

[٣١] فتغير[٢] موضع القمر بزيادة التعديل [هـ ١٦و] على الخاصة ونقصانه يكون لهذا.[٣] وهذا مما تفردت به، على وجه لم يبق إشكال أصلا.[٤]

[٣٢] ثم للقمر اختلاف وهوالتفاوت بين موضعيه من منطقة المائل والممثل، بناء على أن بعدهما عن العقدتين يتفاوت. وهذا لم يعتبر في بعض الزيجات لقلته.

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[١] القمر: الكلمة، سقطت [ج]

[٢] فتغير: فتعين [هـ]

[٣] لهذا: لها واحد [هـ]

[٤] إشكال أصلا: إشكالا صلا [هـ]

in the direction of the anomalistic (epicycle), and the sum of the two motions is observable until it reaches the maximum value, which is approximately one third (of a revolution) from the apogee, since the maximum value of the equation in the smaller epicycle occurs around this limit. Next, it (the equation) decreases until (the anomalistic epicycle) reaches the perigee of the eccentric, in which case the moon is at the perigee of the smaller (epicycle), and there is no equation. Next, it (the anomalistic epicycle) departs (from perigee), and the equation becomes subtractive, because the motion of the anomaly becomes slower, and because the perigee of the smaller (epicycle) moves opposite to it until it reaches the apogee.

[31] The change in the position of the moon by adding or subtracting the equation to the anomaly, is on that account. This (method) is the one which I alone have (proposed), concerning which there will be no further doubt.

[32] Next, the moon has a variation, which is the difference between its (two respective) positions on the cinctures of the inclined and parecliptic (orbs), since their distances from the two nodes differ. This, however, is not taken into consideration in some of the astronomical tables because of its insignificance.

[١] فصل: في الأفلاك[1] العلوية، لحركاتها[2] الطولية.

[٢] [ج ٢٥و] هي أبطأ من الشمس، إذ في غاية سرعتها مستقيمة، تقارنها فتسبقها الشمس، فتطلع هي مشرقة. [ف ٢٧٥ظ] فترجع فتقابلها في وسط الرجعة. [أ ٢٨و] ثم تقف في حدود تثليثها الثاني، فتستقيم بطيئة، ثم تسرع فتقارنها كما مر.

[٣] وجرمها في أواسط الاستقامة صغير، وفي وسط الرجعة [ب ٢٠٦و] عظيم. وأيام استقامتها أكثر من أيام رجعتها. [خ ٢٦ظ] فلها تدوير يتحرك أعلاه إلى التوالي.

[٤] فقال صاحب التحفة: الرجوع لا يدل على التدوير. [أ ٢٨ظ، ب ٢٠٦ظ، ج ٢٥ظ، ف ٢٧٦و، هـ ١٦ظ، خ ٢٧و] فاستدل[3] باختلاف غاية التعديل.

[٥] [ف ٢٧٦ظ] ثم إذا قيس سرعة إلى سرعة، وبطء إلى بطء، واختفاء إلى اختفاء، وجد زمان كل متفاوتا في جميع أجزاء فلك البروج، منتقلا ذلك بانتقال الثوابت. فلا بد من خارج في ثخن ممثل، حركته كالثوابت.

[٦] [أ ٢٩و، ج ٢٦و، خ ٢٧ظ] وحركة الخارج لزحل[4] دقيقتان،

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[1] الأفلاك: أفلاك [أ، ج]

[2] لحركاتها: بحركاتها [ب]، لحركتها [ج]

[3] فاستدل: فالاستدل [هـ]

[4] لزحل: للزحل [ب]

[1] Chapter [6]: On the Orbs (Pertaining) to the Longitudinal Motions of the Superior Planets.

[2] These (planets) are slower than the sun, since at their maximum speed, during their direct motion, they come into conjunction with the sun, which then moves ahead of them, and (the planets) rise in the east. They (i.e. the planets) then retrograde, and they come into opposition with it (i.e. the sun) at the middle of the retrograde motion. [f. 28r] Next, they stop around the (sun's) second trine, and then they move forward. Finally, they speed up and come into conjunction with it (i.e. the sun) as was mentioned (above).

[3] Their (i.e. the planets' apparent) sizes are smaller around the middle parts of the direct motion, and larger at the middle of the retrograde motion. (Moreover), the days of their direct motion are more than the days of their retrograde motion. Therefore, they have epicycles whose upper parts move in the direction of the sequence of the signs.

[4] The author of the *Tuḥfa*, however, maintains that the retrograde motion does not (necessarily) imply an epicycle. [f. 28v] Rather, he draws evidence (for epicycles) from the variation of the maximum value of the equation.

[5] Moreover, if one measures (the period between one) speed and (the next recurrence of the same) speed, (between one) slowness and (the next) slowness, and (between one) invisibility and (the next) invisibility, then one finds that the time for each is variable in each of the degrees of the ecliptic orb, such that these (recurrences) move with the displacement of the fixed stars. An eccentric which is embedded in the thickness of the parecliptic, and which has the same motion as the fixed stars, is thus needed.

[6] [f. 29r] The motion of the eccentric of Saturn is two minutes (per day),

وللمشتري خمس، وللمريخ إحدى وثلاثون.

[٧] /وعلم أنها في الذروة مقارنة للشمس، وفي الحضيض مقابلة لها.[١] فعلم أن حركة تدويرها مثل فضل وسط الشمس على وسطها.

[٨] [ب ٢٠٧و، ف ٢٧٧و، هـ ١٧و] ولها اختلافات: (١)[٢] قوس من منطقة المثل بين طرفي خطين أو دائرتي عرضهما، يخرجان من مركز العالم، يمر أحدهما على مركز التدوير، والآخر على مركز الكوكب، وينتهيان إلى سطح المثل. وغايته[٣] قوس جيبها نصف قطر التدوير، وهو لزحل و ل، وللمشتري يا ل، وللمريخ لط ل. على أن نصف قطر الحامل س ج. وذلك في البعد الأوسط. [أ ٢٩ظ، ج ٢٦ظ، خ ٢٨و] وهو التعديل الثاني في الزيجات، وهو زائد على الوسط مادام الكوكب هابطا من الذروة، ناقص إذا كان صاعدا إليها.

[٩] (٢)[٤] إن نصف قطر التدوير يرى أصغر إذا كان[٥] التدوير فوق البعدين الأوسطين، ويرى أعظم إذا كان تحتهما. فوضع نصف قطر التدوير في البعد الأوسط، وزيادته في البعد الأقرب، في جدولين على نحو ما ذكرنا في القمر. ثم وضع نقصانه في البعد الأبعد، فيوضع

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[١] وعلم ... لها: العبارة، شرح [أ، ب]

[٢] (١): ١ [أ، ب، ج، ف، هـ، خ]

[٣] غايته: غايتها [ب]

[٤] (٢): ٢ [أ، ج]، سقطت [ب، ف، خ]

[٥] كان: +«صاعدا إليها»، ثم شطبت [ب]

that of Jupiter is five (minutes per day), and that of Mars is thirty one (minutes per day).

[7] It was (already) indicated that they (i.e. the superior planets) are in conjunction with the sun at the epicyclic apogee, whereas they are in opposition to it at the epicyclic perigee. Thus, it is deduced that the motions of their epicycles are equal to the difference between the mean motion of the sun and their (respective) mean motions.

[8] They have variations: 1) (The first variation is) an arc on the cincture of the parecliptic marked between the ends of two lines, or (between) their (corresponding) latitude circles, which are issued from the center of the earth, and which end at the surface of the parecliptic, such that one of them passes through the center of the epicycle, and the other (line passes) through the center of the planet. The maximum value (of the first variation) is an arc whose sine is (equal to) the radius of the epicycle when it is at the mean distance, this (radius) being 6;30 (parts) for Saturn, 11;30 (parts) for Jupiter, and 39;30 (parts) for Mars, and assuming that the radius of the deferent is (equal to) 60;0 (parts). [f. 29v] This (variation) is the second equation in the astronomical tables, and it is additive to the mean (longitude of the center of the epicycle) as long as the planet is descending from the epicyclic apogee, and subtractive while ascending towards it.

[9] 2) The radius of the epicycle is seen smaller when the epicycle is farther than the two mean distances, and it is seen bigger when it is closer than them. Thus, the (values) of the radius of the epicycle at the mean distance, and the increase (in its size) when it is at the nearest distance, are put in two tables, in a manner similar to what we mentioned in the case of the moon. The decrease in its size at the farthest distance, (together with its size at the mean distance), are then put into

جدولان آخران لأجل النقصان، كما وضعا[١] للزيادة.

[١٠] (٣)[٢] تشابه الحركة حول مركز معدل المسير، وهو نقطة[٣] على خط الأوج والحضيض، واقعة[٤] في طرف الأوج، بعدها عن مركز الخارج كبعده عن مركز العالم. بعد كل واحد في زحل جـ كه،[٥] وفي المشتري[٦] ب مه، وفي المريخ و ح.[٧] وقطر الذروة والحضيض يحاذي هذه النقطة.

[١١] [ف ٢٧٧ظ] فأقول: لا بد من خارج مركز، مركزه متوسط بين مركز معدل المسير وبين نقطة ظنوها مركز الخارج، وفي ثخنه تدوير محيط بالتدوير ذي الكوكب، بعد ما بين مركزيهما مثل بعد مركز الخارج الذي أثبتناه عن مركز معدل المسير، وهو في المريخ جـ ح.[٨]

[١٢] فإذا كان المحيط في الأوج، فذو الكوكب في حضيض المحيط. وحركة المحيط مثل الخارج: أعلاه إلى التوالي، وأسفله إلى خلافه. فإذا وصل المحيط إلى حضيض الخارج، إرتقى مركز ذي الكوكب

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[١] وضعا: الكلمة، سقطت [ج]

[٢] (٣): ٣ [أ، ب، ج، ف، خ]

[٣] نقطة: نقط [ج]

[٤] واقعة: واقع [ج]

[٥] جـ كه: جـ له [ب]

[٦] في المشتري: العبارة، سقطت [ب]

[٧] و ح: و مه [ب]، و مد [ج]

[٨] جـ ح: ج ما [ب]

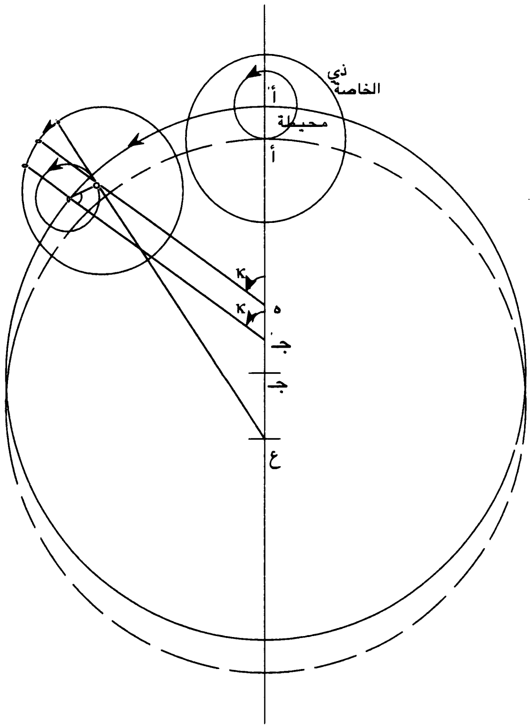
two more tables for the decrease, as they were put for the increase.

[10] 3) The uniformity of the motion is around the (equant) center of the mean motion, which is a point on the apsidal line of the eccentric, which falls on the side of the apogee, such that its distance from the center of the eccentric is equal to the latter's distance from the center of the earth. The distance of each (of the centers) is: 3;25 (parts) in (the case) of Saturn, 2;45 (parts) in that of Jupiter, and 6;0 (parts) in that of Mars. Moreover, the diameter of (the epicycle which passes through) the epicyclic apogee and perigee is in line with this point.

[11] I, however, say that it is necessary to have an eccentric, whose center is half way between the equant center and the point which was (originally) thought to be the center of the eccentric. An epicycle which surrounds the planet-carrying epicycle is embedded in its (i.e. the eccentric's) thickness, such that the distance between their two centers is equal to the distance between the center of the eccentric which we (just) posited, and the equant center, this being 3;0 (parts) in the case of Mars.

[12] When the surrounding (epicycle) is at the (eccentric) apogee, then the planet-carrying one is at the perigee of the surrounding (epicycle). (Moreover), the motion of the surrounding (epicycle) is similar to that of the eccentric: its upper part (moves) in the direction of the sequence of the signs, while its lower part (moves) in the opposite (direction). Thus, when the surrounding (epicycle) reaches the apogee of the eccentric, then the center of the planet-carrying (epicycle) rides

على ذروة المحيط. فيكون بعد مركز ذي الكوكب دائما بعدا متساويا عن نقطة ظنوها مركز الخارج. [أ ٣٠و، ب ٢٠٧ظ، ج ٢٧و، خ ٢٨ظ] وتكون حركة ذي الكوكب متشابهة حول مركز معدل المسير، لأن مركز ذي الكوكب، إذا كان في الأوج،[١] كان في حضيض المحيط، وحركة الحضيض إلى خلاف التوالي. والتشابه[٢] يكون في طرف الأوج، على عكس ما مر في القمر. [ف ٢٧٨و، هـ ١٧ظ]



شكل ٣٩

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[١] في الأوج: العبارة، فوق السطر [ب]

[٢] والتشابه: فالتشابه [ج]

over the apogee of the surrounding (epicycle). (Therefore), the distance between the center of the planet-carrying (epicycle) and a point, which was (originally) thought to be the center of the eccentric, is (always) the same distance. [f. 30r] (Moreover), the movement of the (center of the) planet-carrying (epicycle) around the equant center is uniform, since when the center of the planet carrying (epicycle) is at the (eccentric) apogee, it is also at the perigee of the surrounding (epicycle), and the motion of this perigee is in the direction opposite to the sequence of the signs. Uniformity (of motion) is thus (around a point which falls) on the side of the (eccentric) apogee, in contrast to what was mentioned (above) in the (case of the) moon.

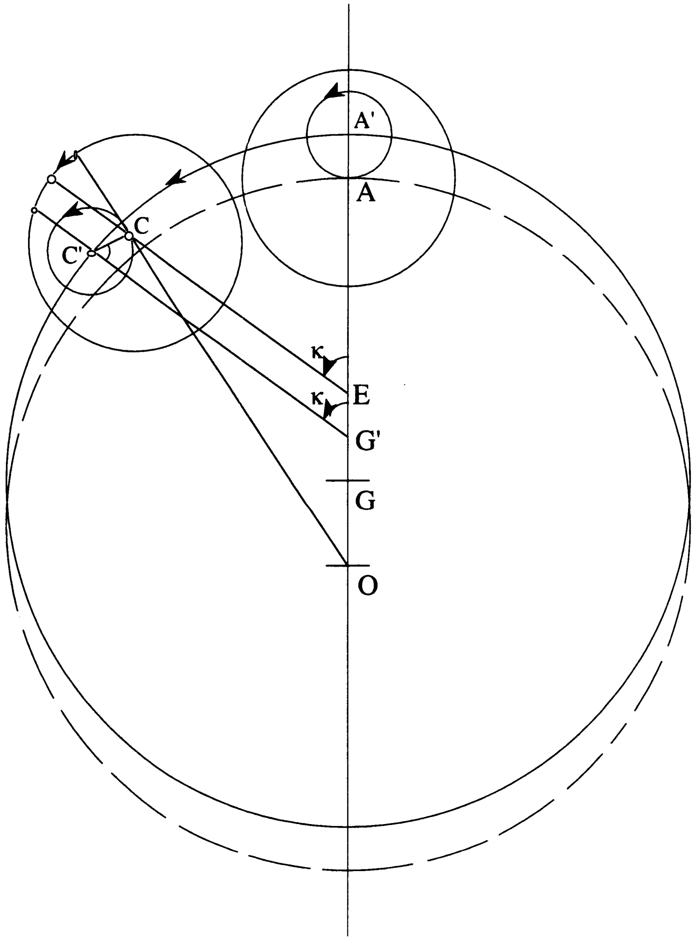

FIGURE 39

[١٣] /ثم لا بد من حافظ لوضع التدوير، يتحرك مثل المحيط إلى خلاف جهته، أو من جعل[١] حركة التدوير بمقدار حركة المحيط والخاصة كما عرف[٢] في القمر.

[١٤] [خ ٢٩و] وإشكال المحاذاة لا يرد، لأن القطر محاذ لنقطة تتشابه الحركة حولها، وهي مركز معدل المسير. فهذا[٣] الاختلاف ينقص[٤] من الوسط ويزاد على الخاصة، مادام التدوير هابطا من الأوج، ويعكس إذا كان صاعدا. [أ ٣٠ظ، ب ٢٠٨و، ج ٢٧ظ، ف ٢٧٨ظ] فتعين موضع الكوكب بهذا العمل دل على التشابه والمحاذاة عند مركز معدل المسير.

[١٥] فيرد عليه أن هذا الاختلاف شيء واحد، فنسبته /إلى منطقة التدوير لا تكون كنسبته[٥] إلى منطقة معدل المسير، التي يعتبر بها الوسط. فكيف يصح هذا العمل؟

[١٦] [هـ ١٨و، خ ٢٩ظ] /فالجواب أن زاوية التعديل التي تزاد على الخاصة أو تنقص منها ما يكون عند مركز التدوير. فهذه الزاوية، إذا وضعت على مركز العالم، فهي التي تزاد أو تنقص من منطقة معدل

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[١] /ثم ... جعل: العبارة، شرح [ج]؛ جعل: +«المسير» [ج]

[٢] عرف: عرفت [ج]، مر [خ]

[٣] فهذا: وهذا [ج]

[٤] ينقص: الكلمة، غير واضحة [ب]

[٥] /إلى ... كنسبته: العبارة، سقطت [ب]

[13] Next, it is necessary to: have either an (orb) which retains the position of the epicycle, which moves (at a speed) equal to that of the surrounding (epicycle) and opposite to its direction, or to make the epicyclic motion equal to the (sum of the) motions of the surrounding (epicycle) and the anomaly, as is known in the (case of the) moon.

[14] The problem of the prosneusis does not arise, because the diameter (which passes through the mean epicyclic apogee and perigee) is in line with a point around which the motion is uniform, namely the equant center. The (above mentioned) variation is subtracted from the mean (longitude), and is added to the anomaly, as long as the epicycle is descending from the (eccentric) apogee, and conversely, if it is ascending. [f. 30v] Therefore, the determination of the location of the planet through this procedure proves the uniformity (of motion), and the alignment around the equant center.

[15] An objection arises against the above, (namely) that this variation is one entity, whereas ascribing it to the cincture of the epicycle is not the same as ascribing it to the cincture of the equant (orb). So how could this procedure be correct?

[16] The response is that the equation angle, which is added or subtracted from the anomaly, is the one which is (measured) at the center of the epicycle. If, however, this angle were placed at the center of the world, then it would be the angle that would be added or subtracted on the cincture of the equant (orb),

المسير، كما عرفت في الشمس.

[١٧] ومما يختص بالمريخ، أن بعده عن[١] الشمس في المقارنة [ف ٢٧٩و] أكثر من بعده عنها في المقابلة، لأن أقل بعد المقارنة بقدر قطر تدوير المريخ، [أ ٣١و] وهو عط ح. وذلك[٢] حين تكون الشمس في الأوج، ومركز تدوير المريخ في حضيض الخارج. وأكثر بعد المقابلة بقدر قطر ممثل الشمس، وهو نجـ، وغلظ متمم[٣] المريخ، [ب ٢٠٨ظ] وهو يب ح،[٤] وغلظ متمم الشمس، وهو د. فالمجموع سط، وذلك حين يكونان[٥] في الأوجين. ويعرف هذا من نصف قطر التدوير، وما بين المركزين.[٦]

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[١] عن: من [ج]

[٢] وذلك: ووذلك [ج]

[٣] متمم: +«التدوير»، بعدها، ثم شطبت [ب]

[٤] يب ح: يب مخ [ب]

[٥] يكونان: يكون [ب]

[٦] /فالجواب...المركزين: العبارة، شرح [ف]

as is known in (the case) of the sun.

[17] Among (the points) which are specific to Mars, is that its distance from the sun during conjunction is larger than its distance from it during opposition; (this is so) because, (on the one hand), the minimum (value of the) distance (between the sun and Mars) at conjunction is equal to the diameter of the epicycle of Mars, [f. 31r] this being 79;0 (parts). This (occurs) when the sun is at the eccentric apogee, and the center of the epicycle of Mars at the eccentric perigee. (On the other hand), the maximum (value of the) distance (between the sun and Mars) at opposition is equal to (the sum of) the diameter of the parecliptic of the sun, this being 53, plus the thickness of the complementary solid of Mars, this being 12;0 (parts), plus the thickness of the complementary solid of the sun, this being 4. The sum is 69, and this (occurs) when they (i.e. the sun and Mars) are at the two apogees. The above (values) are derived from the (values) of the radius of the epicycle, and the distance between the two centers.

[١] [أ ٣٢و، ب ٢٠٩و، ج ٢٨ظ، ف ٢٧٩ظ، هـ ١٨ظ، خ ٣٠و]
فصل: في أفلاك السفليين، لحركتهما الطولية.

[٢] يقارنان الشمس، وحركتهما في غاية السرعة، في وسط الاستقامة، وكذا في وسط الرجعة.

[٣] ولا تبعد[١] الزهرة عنها بأكثر [خ ٣٠ظ] من مز درجة، وعطارد بأكثر من كز[٢] درجة. وهما في الاستقامة أكثر لبثا وأصغر جرما.

[٤] فلكل تدوير أعلاه يتحرك إلى التوالي، وأسفله إلى خلافه. والبعد عن الشمس بقدر ما يقتضيه نصف [ف ٢٨٠و] قطر التدوير.

[٥] ثم إذا قيس حال إلى حال لم توجد متشابهة. فالتدوير في ثخن خارج مركز، حركته مثل وسط الشمس، فمركز التدوير ملازم لمركز الشمس.

[٦] ثم الجزء الذي يوجد البطء فيه أشد، والزمان أقل، ينتقل بانتقال الثوابت. فلا بد من ممثل يتحرك كالثوابت.

[٧] [أ ٣٢ظ، ج ٢٩و] ثم في الزهرة كل حال يوجد في جزء من الخارج، [ب ٢٠٩ظ] وضده يوجد في مقابلته. [خ ٣١و] بخلاف عطارد، فإن بعده [ف ٢٨٠ظ] الأقرب الدال عليه غاية عظم نصف قطر

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[١] تبعد: الكلمة، في الهامش [ب]
[٢] كز: لو [ب]

[1] [f. 32r] Chapter [7]: On the Orbs (Pertaining) to the Longitudinal Motions of the Two Inferior Planets.

[2] Both (planets) come into conjunction with the sun, while at the maximum speed of their motion, at the middle of the direct motion, and similarly at the middle of retrograde motion.

[3] The distance of Venus from it (i.e. the sun) does not exceed 47 degrees, and that of Mercury does not go beyond 27 degrees. Moreover, both of them have longer durations and smaller (apparent) sizes during direct motion.

[4] Each of them thus has an epicycle, whose upper part moves in the direction of the sequence of the signs, and whose lower part moves in the opposite direction. The distance from the sun is equal to the amount entailed by the radius of the epicycle.

[5] Next, if one compares the various positions (of these planets, one finds that) they are not similar. The epicycle should thus be (embedded) in the thickness of an eccentric whose motion is equal to that of the mean sun, and the center of the epicycle is inseparable from the center of the sun.

[6] Furthermore, the point at which the motion is slowest and the (slow) duration is shortest, moves with the motion of the fixed stars. It is therefore necessary to have a parecliptic which has the same motion as the fixed stars.

[7] [f. 32v] Next, in (the case of) Venus, all conditions occurring at a (specific) point of the eccentric, will have contrary (conditions) occurring at the (point) diametrically opposite to it. This is contrary to (the case of) Mercury, since (the position of) its closest distance (from the center of the world), which is inferred from the maximum size of the radius of

التدوير، ليس في مقابلة بعده الأبعد، الدال عليه غاية[1] صغره، بل في تثليثه، فهو فيهما أعظم، ثم في المقابلة، ثم في البعد الأبعد.

[٨] بخلاف القمر، فأن نصف قطر تدويره[2] في البعد الأبعد ومقابلته سواء، والبعد الأقرب في القمر في التربيعين.

[٩] فدل أن مدار مركز التدوير ليس دائرة، لأن النقطتين من محيطه أقرب من سائر النقط إلى نقطة[3] في داخله، وهي مركز العالم، والدائرة لا تكون كذلك. [هـ ١٩و] فمداره شكل إهليلجي أو بيضي. فله أوجان يكون فيهما في البعد الأبعد، وفي أحديهما[4] في مقابلته.

[١٠] فله خارجا مركز: أحدهما في ثخن المثل، وهو المدير. بعد مركزه عن مركز العالم و، في طرف البعد الأبعد. والآخر في ثخن المدير، بعد مركزه عن مركزه جـ، على أن نصف[5] قطر الحامل ستون. والتدوير في ثخنه، والكوكب في التدوير.

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[1] غاية: +«عظم» [ج]

[2] تدويره: تدويرها، ثم صححت في الهامش [ب]

[3] نقطة: النقطة، ثم صححت في الهامش [ب]

[4] أحديهما: +«هما»، أضيفت في الهامش [ب]

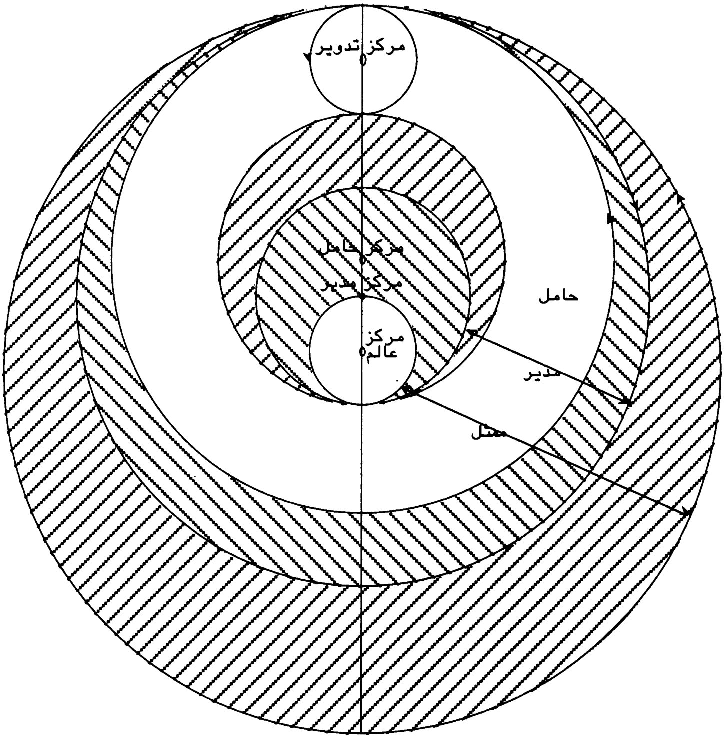
[5] نصف: الكلمة، سقطت [أ، ب]

the epicycle, is not diametrically opposite to (the position of) its farthest distance, which is inferred from its minimum size. Rather it (i.e. the closest distance) is at the two trińes, where (the radius of the epicycle) is largest. The (distance) then (increases) at the diametrically opposite position, and (it increases) further at the (position) of its farthest distance.

[8] This (case of Mercury) is also different from (that of) the moon where the radius of its (i.e. the moon's) epicycle, both at the farthest distance (from the earth), and at the position which is diametrically opposite to it, are equal. Moreover, the closest distance in the (case of the) moon is at the two quadratures.

[9] (The above), therefore, proves that the path of the center of the epicycle (in the case of Mercury) is not a circle, because (there are only) two points on its circumference which are closer than the remaining points to a point inside (his circumference), that is the center of the world. A circle cannot be so. Its path, therefore, has an elliptical or an egg-like shape. It (i.e. the path of Mercury's epicycle center) thus has two apogees at which it will be at the farthest distance, one of them being diametrically opposite the other.

[10] It (i.e. the path of Mercury's epicycle center) also has two eccentrics: one of the two is (embedded) in the thickness of the parecliptic, and is the director, the distance of whose center from the center of the earth is 6 (parts), (marked) on the side of the farthest distance. The other (eccentric) is (embedded) in the thickness of the director, (such that) the distance between their centers is 3 (parts), assuming that the radius of the deferent is 60 (parts). The epicycle is then (embedded) in its thickness (i.e. that of the second eccentric), and the planet is on the epicycle.



شكل ٤١

[١١] فالأوج الأول يتحرك بالثوابت. والثاني بالمدير على خلاف التوالي، كوسط الشمس. والحامل إلى التوالي، ضعفه.

[١٢] فإذا كان التدوير في الأوجين، فمن مركز العالم إلى مركز المدير[١] و؛ ومنه إلى مركز الحامل ج؛ ومنه إلى مركز التدوير س؛ فالمبلغ سط. فيتحرك الأوج الثاني ومركز الحامل بالمدير إلى خلاف

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[١] المدير: +«التدوير»، قبلها، ثم شطبت [ب]

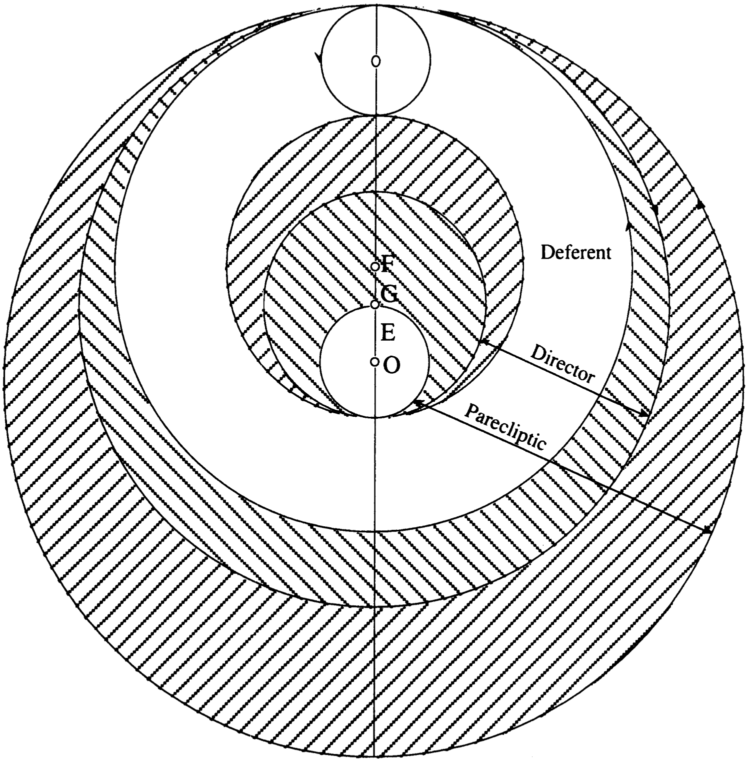
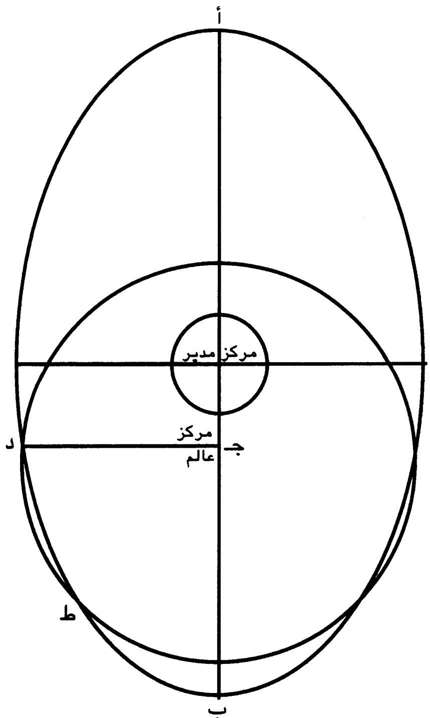


FIGURE 41

[11] The first apogee is moved by the (motion) of the fixed stars. The second (apogee) is moved by the (motion) of the director in the direction opposite to the sequence of the signs, (and it is) the same as the (motion) of the mean sun. The deferent moves at twice (the above speed), in the direction of the sequence of the signs.

[12] When the epicycle is at the apogees, then (in the first case) the (distance) from the center of the world to the center of the director is 6 (parts); (the distance) from it (i.e. the center of the director) to the center of the deferent is 3 (parts); (and finally, the distance) from it (i.e. the center of the deferent) to the center of the epicycle is 60 (parts). The sum is 69 (parts). The second apogee, together with the center of the deferent, move by (the motion of) the director, in the direction opposite to

التـوالي، والتـدوير بالحـامل إلى التـوالي. فـالتـقى الأوج الثـاني ومركـز التـدوير في مـقابلة الأوج الأول. ومركز [أ ٣٣و] الحـامل هنا بين مـركـز المدير ومركـز العالم. فالبعد[١] من مركز العالم إلى مركز التدوير نز. فإذا تم الدور حصل من حركة مركز التدوير هذا الشكل: طوله قكو، وغاية[٢] عـرضـه قـيـد، ووسـطه مـركـز [خ ٣١ظ] المدير [ج ٢٩ظ] بهـذه الصـورة (شكل ٤٣). [ب ٢١٠و، ف ٢٨١و]



شكل ٤٣

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[١] فالبعد: +«فالمدير»، قبلها، ثم شطبت [أ]

[٢] غاية: الكلمة، سقطت [ج]

the sequence of the signs, whereas the epicycle moves by (the motion of) the deferent, in the direction of the sequence of the signs. The second apogee and the center of the epicycle then coincide at (a point which is) diametrically opposite to the first apogee. (At this position,) the center [f. 33r] of the deferent is between the center of the director and the center of the world, and the distance from the center of the world to the center of the epicycle is 57 (parts). Moreover, when one rotation is completed, the motion of the center of the epicycle produces a shape whose length is 126 (parts), and maximum width is 114 (parts). Its center is the same as the center of the director, as in this (attached) figure (figure 43).

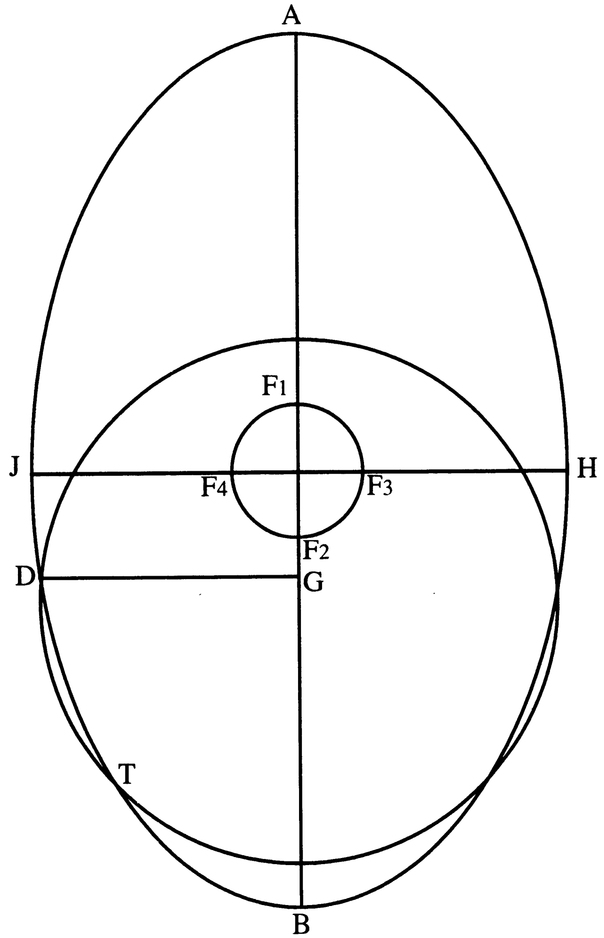

FIGURE 43

[١٣] فالبعد الأبعد نقطة أ، ويقابله[١] ب، ومركز العالم جـ. فنخرج منه خطا يصل إلى محيط الشكل على نقطة د، قائما على أب. فأن جـ د أصغر من جـ ب، لأن جـ ب مقداره نز، وهو نصف غاية العرض، و جـ د أقل من نصف غاية العرض، لأن العرض يقل شيئا فشيئا إذا جاوز المنتصف، وهو مركز المدير.[٢] فإذا فصل من جـ ب مقدار جـ د، وأدير[٣] دائرة، فتخرج الدائرة عن الشكل عند نقطة ط، ثم تدخل عند نقطة د. لأن كل دائرة [أ ٣٣ظ] تعمل في الشكل البيضي، قطرها مثل عرضه في أي موضع كان، فقطعتان منها تخرجان عن الشكل في طرفيه، لأن العرض يقل في هذا الشكل أكثر مما[٤] يقل في الدائرة، [خ ٣٢و] لأن هذا الشكل ينتهي إلى الزاوية بخلاف الدائرة. فبعد المجاوزة عن نقطة د يكون الخط الخارج من جـ إلى محيطه أقصر[٥] من جـ د، [ف ٢٨١ظ، هـ ١٩ظ] إلى أن[٦] ينتهي إلى غاية القصر؛ ثم يطول إلى أن ينتهي إلى نقطة ط، فيصير مساويا لخط جـ د؛ ثم يطول إلى أن ينتهي إلى مقابلة البعد الأبعد.

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[١] يقابله: مقابله [ب]

[٢] المدير: التدوير [ب]

[٣] أدير: لاير [ج]

[٤] مما: ممن، ثم صححت [أ]

[٥] أقصر: أقطر [هـ]

[٦] إلى أن: إلى غاية أن، ثم شطبت غاية [أ]

[13] Let the farthest distance be point A, and (the point which is) diametrically opposite to it be (point) B, and let the center of the world be (point) G. From G we issue a line perpendicular to AB, such that it intersects the circumference of the (above) shape at point D. Now GD is smaller than GB, because GB is equal to 57 (parts), which is half the maximum width, whereas GD is less than half the maximum width, since the width decreases gradually after it passes the middle (point), which is the center of director. Thus if (the length of) GD is marked on GB, and if a circle is drawn (accordingly), then this circle goes out of the (confines of the above) shape at point T, and then it enters back at point D. This is so because if a circle [f. 33v] is marked over an egg-like shape, such that the diameter of the former is equal to the width of the latter at any (desired) position, then two sections (of the circle) go out of the (confines of the egg-like) shape at its two sides, because the width in this shape decreases more than it does in a circle, since this shape, contrary to the circle, ends in an angle. Thus, after passing past point D, (a line) issued from (point) G to its circumference (i.e. that of the egg-like shape), will be shorter than GD, until it reaches its minimum length; then it becomes longer until it reaches point T, where it becomes equal to line GD; then it extends until it reaches the (point which is) diametrically opposite to the farthest distance (of the center of the epicycle).

[١٤] وأما الاختلافات، [ج ٣٠و] فكما في العلوية، فأفلاك الزهرة كأفلاكها. أما عطارد، فالتشابه والمحاذاة فيه بحسب نقطة متوسطة بين مركزي المدير والعالم. وقال صاحب التذكرة: «لم يتيسر لي توهم ذلك على ما ينبغي». وها أنا أذكر ما يسره الله تعالى لي، فأقول:

[١٥] حركة مركز التدوير تجعل متشابهة حول مركز المدير، بالطريق الذي ذكر في القمر. /فنثبت خارج مركز، مركزه متوسط بين النقطة[١] التي ظنوها مركز الخارج وبين مركز المدير. فيكون بعده عن مركز المدير درجة ونصفا. ثم نثبت تدويرا في ثخن الخارج، ثم في ثخن هذا التدوير التدوير ذا الكوكب، بعد مركزه عن مركز التدوير الأول كبعد مركز الخارج عن مركز المدير؛ حركة التدوير الأول كحركة الخارج، أعلاه إلى التوالي، وأسفله إلى خلافه. فيلزم تشابه حركة مركز التدوير حول مركز المدير.[٢] [ب ٢١٠ظ] فلزم أن تكون غاية الاختلاف بقدرما يقتضيه خروج مركز المدير عن مركز العالم، وهو ستة أجزاء، والواقع بقدر ما يقتضيه نصف ذلك. فعلم أن لمركز التدوير ميلا طوليا.

[١٦] وطريقه أن نثبت ثلاثة أفلاك محيط بعضها ببعض، كلها حاوية للمدير بحيث مركزها مركزه. وحركة الأول مثل المدير، والثاني

[١] النقطة: النقط [ج]

[٢] /فنثبت ... المدير: العبارة، شرح [أ]

[14] As for the (equational) variations, they are similar to those of the superior (planets), since the orbs of Venus are similar to the latter's orbs. As for Mercury, the uniformity and alignment in it are with respect to a point which is halfway between the centers of the director and the world. The author of the *Tadhkira* says: "It is not easy for me to properly visualize this (point)." So I will mention (below) what God, may He be exalted, had facilitated for me. I thus say:

[15] The motion of the center of the epicycle is made uniform around the center of the director, in the manner that was mentioned in the moon. We posit an eccentric, whose center is halfway between the point which was thought to be the center of the eccentric and the center of the director. Its distance from the center of the director will be one and one half of a degree (sic., i.e. 1;30 parts). Next, we posit an epicycle (embedded) in the thickness of the eccentric, and in the thickness of this epicycle we posit the planet-carrying epicycle, such that the distance between the centers of (the second) and the first epicycles are equal to the distance between the center of the eccentric and the center of the director; the motion of the first epicycle is equal to the motion of the eccentric, and its upper part (moves) in the direction of the sequence of the signs, whereas its lower part (moves) in the opposite (direction). The uniformity of the motion of the center of the (planet carrying) epicycle around the center of the director is thus entailed. (The above) also requires that the maximum variation (i.e. equation of center) is equal to (the value) which is required by the eccentricity of the center of the director from the center of the world, which is six parts, whereas in reality it is equal to (the value) which is entailed by half that (amount). Therefore, it is deduced that the center of the epicycle has a longitudinal inclination.

[16] The method (for representing) the above model is to posit three orbs surrounding each other, all of which encompass the director, such that they all have the same center. The motion of the first (orb) is similar to the motion of the director, that of the second

ضعفه على خلاف جهة[1] الأول، والثالث مثل الأول وفي جهته. قطب الأول عند طرف الخط المار على مركز المدير، القائم [خ ٣٢ظ] على خط الأوج والحضيض، محاذ لمنطقة المدير.

[١٧] وفرضنا أولا قطب الثاني غربيا[2] عنه، محاذيا للمنطقة أيضا؛ ونقطة أ نقطة من منطقة المدير، نريد [أ ٣٤و] تحريكه على خط مستقيم، غربية[3] عن قطب الثاني كل بعد نصف غاية الميل، أي درجة ونصف؛ ومركز التدوير محاذيا[4] [ف ٢٨٢و] لها. وقطب الثالث مسامتا لقطب الأول.

[١٨] فلزم[5] من تحريك الأول والثاني أن تتحرك نقطة أ على خط مستقيم، على التوالي، ست درجات. ثم تعود وتتحرك إلى خلاف التوالي ست درجات، حتى تعود إلى الحالة الأولى. وكذا جميع أجزاء المدير، وكذا مركز التدوير.

[١٩] فإذا دار الأول ربع الدور، انطبق نقطة أ على قطب الأول، وحينئذ وصل مركز التدوير إلى الأوج لأنه تحرك ربعا وثلاث درجات،

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[1] جهة: جهته [ب]

[2] غربيا: قريبا [ج]

[3] غربية: قريبة [ج]

[4] محاذيا: محاذية [أ، ب، ف]

[5] فلزم: يلزم [ج]

is twice as much and in the opposite direction of the first, and the third is similar to the first and in its direction. (Moreover), the pole of the first (orb) is at the end of the line passing through the center of the director, which is perpendicular to the apsidal line (of the eccentric), and which is aligned with the cincture of the director.

[17] First, let us consider the pole of the second (orb) to be west of it (i.e. the pole of the first orb), such that it is also aligned with the cincture (of the director); point *A* is a point on the cincture of the director. We want [f. 34r] to move that point on a straight line, such that it is west of the pole of the second orb, at a distance (which is equal) to the entire half of the maximum inclination, that is one and a half degree; the center of the epicycle is also aligned with it (i.e. point *A*). The pole of the third (orb) is in the same direction as the pole of the first.

[18] The movement of the first and the second (orbs) thus results in the movement of point *A* through six degrees along a straight line, in the direction of the sequence of the signs. It then turns back and moves six degrees, in the direction opposite the sequence of the signs, until it returns to the first position. Similarly for all the points of the director, and also the center of the epicycle.

[19] If the first (orb) rotates through a quarter of a revolution, then point *A* coincides with the pole of the first (orb), and the center of the epicycle reaches the apogee; (this is so) because it moves a quarter (of a revolution) and three degrees,

لأن حركة الاختلاف إلى التوالي؛ ولا اختلاف هنا،[1] لانطباقها على قطب الأول.

[٢٠] فإذا أتم الأول[2] نصف الدور، تكون نقطة أ في غاية البعد الشرقي عن قطب الأول، وهي ثلاث درجات. وحينئذ يكون بعد مركز التدوير عن الأوج ربع [ج ٣٠ظ] دور وثلاث درجات، لأن الاختلاف زائد حينئذ، لكون حركته على التوالي.

[٢١] ثم يتحرك الأول ربع الدور، فحينئذ تنطبق نقطة أ على القطب. ومركز التدوير في مقابلة الأوج، لأنه تحرك عن البعد الأوسط ربع دور إلا ثلاث درجات، لكون حركة الاختلاف على خلاف التوالي. ولا اختلاف هنا.

[٢٢] ثم نقطة أ تصير غربيا[3] حتى تنتهي إلى الحالة الأولى، وهي النهاية الغربية. فيكون من النقطة المقابلة للأوج إلى مركز التدوير ربع الدور إلا ثلاث درجات، لأن الاختلاف ناقص، لكون حركته[4] إلى خلاف التوالي.

[٢٣] فهذا هو التشابه عند نقطة بين مركز العالم ومركز المدير. والمحاذاة أيضا حاصلة بحسب هذه النقطة.

---

[1] هنا: ههنا [ج]

[2] أتم الأول: ثم للأول [أ، ب]؛ أتم: م [ج]

[3] غربيا: قريبا [ج]

[4] حركته: حركة [أ، ب]

since the motion in variation is in the direction of the sequence of the signs; (moreover), there is no variation (in this case), because it (i.e. point A) coincides with the pole of the first (orb).

[20] Now, if the first (orb) completes half a revolution, then point A will be at the farthest eastward distance away from the pole of the first (orb), that being three degrees. The distance of the center of the epicycle away from the apogee will then be a quarter of a revolution and three degrees; (this is so) because the variation in this case is additive, since its motion (i.e. that of the epicycle) is in the direction of the sequence of the signs.

[21] The first (orb) then moves a quarter of a revolution, at which time point A coincides with the pole. The center of the epicycle will be diametrically opposite to the apogee; (this is so) because it (i.e. the center of the epicycle) moves away from its mean-distance (position) through a quarter of a revolution less three degrees, since the motion of the variation is in the direction opposite to the sequence of the signs. Here (too), there is no variation.

[22] Next, point A becomes westerly, until it reaches the first situation, namely the westward end. (The distance) between the point which is diametrically opposite to the apogee and the center of the epicycle will thus be a quarter of a revolution less three degrees. (This is so) because the variation is subtractive, since its motion is in the direction opposite to the sequence of the signs.

[23] This produces the uniformity (of motion) around a point which is halfway between the center of the world and the center of the director. Alignment is also obtained with respect to this point.

[١] [أ ٣٤ظ، ب ٢١١و، ف ٢٨٢ظ، هـ ٢٠و، خ ٣٣و] فصل :

[٢] للقمر عرض واحد ثابت،[١] وقد مر.

[٣] وللعلوية عرضان: أحدهما ميل المائل عن منطقة الممثل. والمائل دائرة ترتسم على سطح الممثل، مركزها مركز العالم، إذا فرضت منطقة الحامل قاطعة للعالم. وهذا الميل ثابت، غايته لزحل جزءان ونصف، وللمشتري جزء و نصف، وللمريخ جزء.

[٤] والثاني ميل قطر الذروة والحضيض عن منطقة المائل، فإنه ليس في سطحه[٢] ولا في سطح منطقة البروج إلا عند كون مركز التدوير في إحدى الجوزهرين. وبعد ذلك تميل الذروة إلى جهة منطقة البروج، والحضيض إلى خلافها.

[٥] /فنفرض[٣] الرأس في أول الحمل. فإذا كان التدوير فيه، فلا ميل. فإذا [ج ٣١و] فارقه، مال الذروة إلى الجنوب من المائل، وهو جهة المنطقة، إلى أن يصل إلى رأس السرطان، وحينئذ غاية الميل. ثم ينقص إلى أن يصل إلى رأس الميزان، فلا ميل. فإذا فارقه، مال الذروة إلى جهة شمال المائل، وهي جهة المنطقة، إلى أن يصل إلى الغاية عند رأس الجدي. ثم ينقص [خ ٣٣ظ] إلى أن يعود إلى الحالة[٤] الأولى عند رأس الحمل.

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[١] ثابت: +«غاية»، ثم شطبت [ج]

[٢] سطحه: سطح [ج]

[٣] فنفرض: فتعرض [هـ]

[٤] الحالة: حالة [ف]

[1] [f. 34v] Chapter [8]:

[2] The moon has one fixed (inclination in) latitude, and it has (already) been mentioned before.

[3] The superior planets have two inclinations: the first is the inclination of the inclined (orb) away from the cincture of the parecliptic. If the cincture of the deferent is assumed to pass through the (center of the) world, (then) the inclined (orb) is a circle which is marked on the surface of the parecliptic, such that its center is the center of the world. This inclination is fixed, and it amounts to two and a half degrees in (the case of) Saturn, one and a half degrees in (the case of) Jupiter, and one degree in (the case of) Mars.

[4] The second is the inclination of the diameter, (which connects) the (true) apogee and the (true) perigee (of the epicycle), away from the cincture of the inclined (orb), since it (i.e. this diameter) only falls in the plane (of the inclined orb) or in the plane of the cincture of the ecliptic, when the center of the epicycle is at one of the two nodes. Apart from those (nodes), the apogee inclines in the direction of the cincture of the ecliptic, and the perigee in the opposite (direction).

[5] Let us assume that the head is at the beginning of Aries. Thus if the (center of the) epicycle (falls) on it, then there is no (second) inclination. If (the center of the epicycle) departs from (the head), then the (epicyclic) apogee inclines south of the inclined (orb), which is the direction of the cincture (of the ecliptic), until it (the epicycle) reaches the beginning of Cancer (ninety degrees from the node,) where the maximum inclination (occurs). It (i.e. the inclination) then decreases until it reaches the beginning of Libra, where there is no inclination. If then (the center of the epicycle) departs (from the beginning of Libra), then the (epicyclic) apogee inclines in the direction north of the inclined (orb), which is the direction of the cincture (of the ecliptic), until (the epicycle) reaches the (point of) maximum (inclination) at the beginning of Capricorn. Next, (the inclination) decreases until it reaches the first condition at the beginning of Aries.

[٦] واعلم أن غاية هذا الميل عند مركز التدوير، لزحل د ل،[١] وللمشتري ب ل، وللمريخ ب يه.[٢] لكن عند [ف ٢٨٣و] مركز العالم،[٣] ميل الذروة أصغر من ميل الحضيض، إذ ذلك أبعد عن مركز العالم. وأيضا الشمالي أصغر من الجنوبي، لأن الأوج في الشمال[٤] [أ ٣٥و، ب ٢١١ظ، هـ ٢٠ظ] وغايته لزحل.[٥]

	لزحل		للمشتري		للمريخ	
	ش	جـ	ش	جـ	ش	جـ
غاية ميل الذروة	ة كو	ة كح	ة كد	ة كه	ة كب	ة كز
غاية ميل الحضيض	ة لجـ	ة له	ة له	مه لح	جـ كب	و و

[١] د ل: د أ [ب]

[٢] ب يه: ب له [ب]؛ للمريخ ب يه: العبارة، سقطت [ف]

[٣] العالم: الكلمة، سقطت [ب، ف]

[٤] /فنفرض...الشمال: العبارة، شرح [ف]

[٥] لزحل: الكلمة، سقطت [أ، ج]

[6] Note that the maximum of this inclination at the center of the epicycle is 4;30 (degrees) for Saturn, 2;30 for Jupiter, and 2;15 for Mars. At the center of the world, however, the inclination of the apogee is less than the inclination of the perigee, since the former is farther (than the latter) from the center of the world. Moreover, the northern (inclination) is less than the southern one, because the (deferent's) apogee is in the north. [f. 35r] Its maximum (value) is for Saturn.

	Saturn		Jupiter		Mars	
	North	South	N.	S.	N.	S.
Max. Incl. of apogee	0;26	0;28	0;24	0;25	0;22	0;27
Max. Incl. of Perigee	0;33	0;35	0;35	0;38	3;22	6;6

[٧] [ف ٢٨٣ظ] وللسفليين عرضان: (١)[١] ميل المائل[٢] عن الممثل، وهو غير ثابت، بأن [خ ٣٤و] ينقص الميل الشمالي حتى ينطبقا؛ ثم يحصل الجنوبي [ج ٣١ظ] مساويا للأول؛ ثم ينقص حتى ينطبقا؛ ثم يحصل الشمالي كما كان. فهذا دور واحد.

[٨] فمركز التدوير للزهرة إما على الممثل، عند الانطباق، أو شمالي. ولعطارد إما عليه، أو جنوبي أبدا. بأن يكون للمائل حركة طولية، يتم دورته مع العرضي.

[٩] فنفرض أحد الجوزهرين رأس الحمل. ونقطة أ جزء من المائل عليه وقت الانطباق، و ب تقابله. فما يلي السرطان، وهو جـ، مال شمالا، و د جنوبا. وتحرك أ بالتوالي، فصار شماليا، و ب جنوبيا. فأذا وصل أ عند رأس الميزان، حصل الانطباق، فما يلي السرطان، وهو الآن د، يميل جنوبا. وما يلي رأس الجدي، وهو الآن جـ، يميل شمالا. فنقطة أ متوجهة[٣] نحو الجدي فيصير شماليا، و ب جنوبيا. وهكذا أبدا.

[١٠] فمركز التدوير للزهرة[٤] نقطة أ ولعطارد نقطة ب.

[١١] (٢)[٥] ميل قطر التدوير المار بالذروة والحضيض، فإنه ليس

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[١] (١): ١ [أ، ب، ج، ف، هـ]، سقطت، [خ]

[٢] المائل: الكلمة، سقطت [ج]

[٣] متوجهة: متوجه [ج]

[٤] للزهرة: +«و»، بعدها [ج]

[٥] (٢): ٢ [أ، ب، ج، هـ، خ]، الثاني [ف]

[7] The two inferior planets have two inclinations: (1) The inclination of the inclined orb away from the parecliptic, and it is not fixed. The northern inclination decreases until they (i.e. the inclined and the parecliptic orbs) coincide; next, the southern (inclination) equals the first (northern inclination); it will then decrease until they (i.e. the inclined and parecliptic orbs) coincide; (finally) the northern (inclination) returns as it was (in the first position). This (cycle covers) one whole revolution.

[8] The center of the epicycle for Venus, therefore falls either on the parecliptic, during coincidence (between the parecliptic and the inclined orbs), or always to its north. As for Mercury, (the center of its epicycle would fall) either on it (i.e. the parecliptic), or always to its south. (This is produced) by assuming that the inclined (orb) has a longitudinal motion, such that its rotation would be completed together with the (motion in) latitude.

[9] We (now) assume that one of the two nodes is (at) the beginning of Aries. (Let) point *A* be a part of the inclined (orb) which falls on it (i.e. the beginning of Aries) at the time of coincidence (between the parecliptic and the inclined orbs, and (let point) *B* be (the point which is) diametrically opposite to it. That (point) which is adjacent to (the beginning of) Cancer, namely *G*, inclines towards the north, and (point) *D* (inclines) towards the south. (Point) *A* then moves in the direction of the sequence of the signs, and it becomes northerly, while (point) *B* (becomes) southerly. Now, when *A* reaches the beginning of Libra, then coincidence takes place (again). (Next), that (point) which is adjacent to (the beginning of) Cancer, which is now (point) *D*, inclines towards the south. That (point) which is adjacent to the beginning of Capricorn, now being (point) *G*, inclines towards the north. Point *A* then moves towards (the beginning of) Capricorn, and it thus becomes northerly, while *B* (becomes) southerly. This is always the case.

[10] The center of the epicycle for Venus thus (corresponds to) point *A*, and that of Mercury (to) point *B*.

[11] (2) (The second inclination is) the inclination of the diameter of the epicycle which passes through the (epicyclic) apogee and perigee, for it does not

في سطح منطقة المائل إلا عند كون مركز التدوير في الأوج[1] أو الحضيض. وهما عند منتصف ما بين العقدتين. أما إذا زال عن الأوج، مال للزهرة الذروة إلى الشمال، والحضيض إلى الجنوب. وإذا مال عن الحضيض فبالعكس. [أ ٣٥ظ] ولعطارد على العكس.

[١٢] وغاية هذا الميل بالنسبة إلى مركز التدوير للزهرة جزءان ونصف، ولعطارد ستة أجزاء[2] وربع. وبالنسبة إلى مركز العالم [ب ٢١٢و] هكذا.[3]

	للزهرة	لعطارد
غاية ميل الذروة	أ ب	أ مه
غاية ميل الحضيض	و كجـ	د د

[١٣] ولا تفاوت بين الشمال والجنوب.

[١٤] [ف ٢٨٤و، خ ٣٤ظ] (٣)[4] ميل قطر البعدين الأوسطين

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[1] في الأوج: العبارة، سقطت [ج]

[2] أجزاء: الكلمة، غير واضحة [ب]

[3] الجدول التالي ورد في هامش [أ]

[4] (٣): ٣ [أ، ب، ج، هـ، خ]، الثالث [ف]

fall in the plane of the inclined (orb) except when the center of the epicycle is at either the (deferent) apogee or perigee. These (deferent apogee and perigee) are located halfway between the two nodes. If, however, (the center of the epicycle) departs from the (deferent) apogee, then the (epicyclic) apogee of Venus inclines towards the north, while the perigee (inclines) towards the south. If it departs from the perigee, then the opposite (is the case). [f. 35v] The opposite (holds) in the case of Mercury.

[12] The maximum value of this inclination with respect to the center of the epicycle is: two and a half degrees for Venus, and six and one quarter degrees for Mercury. (The corresponding values) with respect to the center of the world are as follows:

	Venus	Mercury
Max. Incl. of Apogee	1;2	1;45
Max. Incl. of Perigee	6;23	4;4

[13] There is no difference between the (above values) in the north or south directions.

[14] (3) (The third inclination is) the inclination of the diameter (joining the two points)

للتدوير، عن سطح مواز لمنطقة المثل. وهو ليس في سطح المائل ولا المثل إلا عند كون[١] مركز التدوير في إحدى العقدتين. فإذا فارقه، فأن[٢] كان ذاهبا إلى الأوج، ففي الزهرة الطرف المتأخر،[٣] أي الشرقي، ويسمى المسائي، مال إلى الشمال، والمتقدم،[٤] وهو الصباحي، إلى الجنوب. [ج ٣٢و] وفي عطارد [هـ ٢١و] على العكس. حتى يصلا إلى الأوج، فحينئذ غاية الميل. ثم ينقص إلى أن ينعدم عند الوصول إلى العقدة الأخرى، ثم يميل المسائي إلى الجنوب، والصباحي إلى الشمال، في الزهرة، وفي عطارد، إلى أن يصلا إلى مقابلة الأوج. ثم يقل إلى أن يحصل الوضع الأول.

[١٥] واعلم أن العقدة الأولى تسمى في الزهرة رأسا، وفي عطارد ذنبا. والأخرى على العكس.

[١٦] [أ ٣٦و] وإنما أثبتوا هذه العروض لأنهم رصدا العلوية عند كون مركز التدوير في البعد الأبعد، /وكذا الأقرب، والكواكب في أي موضع من التدوير. فوجدوها شمالية عن منطقة البروج دائما في البعد الأبعد،[٥] وجنوبية عنها في الأقرب. وأيضا وجدوا جزئين متقابلين من

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[١] كون: الكلمة، سقطت [أ، ب]

[٢] فأن: الكلمة، سقطت [ج]

[٣] المتأخر: الموخر [أ، ج]

[٤] المتقدم: المقدم [ج]

[٥] /وكذا...الأبعد: العبارة، في الهامش [ب]

of the epicycle (which are) at the mean distance (from the apogee and perigee), with respect to a plane which is parallel to the cincture of the parecliptic. (This diameter) is neither in the plane of the inclined orb, nor in that of the parecliptic, except when the center of the epicycle is at one of the two nodes. If it (i.e. the center of the epicycle) departs from (either one of the two nodes), and if in the case of Venus (the center of the epicycle) is moving towards the (deferent's apogee), then the lagging section (of the epicycle), that is the eastern one, which is (also) called the evening one, inclines towards the north, and the leading section, that is the morning one, towards the south. The opposite (holds) in the case of Mercury. (The inclinations continue to increase) until they reach the (deferent) apogee, where the maximum inclination (is obtained). They then start to decrease until they vanish upon arriving at the other node. The evening (section) of (the epicycle of) Venus then inclines to the south, and the morning one to the north, (and conversely) for Mercury, until they reach the (point which is) diametrically opposite the (deferent) apogee. (The inclinations) then decreases until the first situation obtains.

[15] Note that the first node is called a head in the case of Venus, and a tail in the case of Mercury, and conversely for the other (node).

[16] [f. 36r] These latitudes were only posited by observing the superior (planets) while the center(s) of epicycle(s) were at their farthest distance (from the earth), and also (at) the closest distance, and (then noting) in which position of the epicycle(s) the planets were (located). They (i.e. the planets) were invariably found north of the cincture of the ecliptic (while the center of the epicycle was) at the farthest distance, and south of it at the closest (distance). Moreover, two diametrically opposite points on

منطقة البروج، [خ ٣٥و] بحيث كلما كان مركز التدوير [ف ٢٨٤ظ] في أحدهما،[١] والكوكب في الذروة أو الحضيض، كان عديم العرض. وكلما كان مركز التدوير في غيرهما[٢] بين النقطتين، والكوكب في الذروة أو الحضيض، وجدوا ميل الذروة أقل من ميل [ب ٢١٢ظ] الحضيض، فحكموا بأن للحامل ميلا عن منطقة البروج، ثابتا شمالا وجنوبا، وأن هذين الجزئين هما العقدتان.

[١٧] [ج ٣٢ظ] بل إذا كان في إحدى العقدتين، كان في سطح المائل والممثل. وإذا جاوزها، مال الذروة نحو فلك البروج، والحضيض إلى خلافه، وإلا لما كان بعد الذروة عنه أقل دائماً من بعد الحضيض.

[١٨] [أ ٣٦ظ، ف ٢٨٥و، خ ٣٥ظ] فصاحب التذكرة أثبت للميل الثاني ثلاث كرات محيطة بالتدوير، مركزها مركزه. منطقة الأولى في سطح منطقة المائل. فندير دائرة تمر بقطبي التدوير، قطب الأولى على تلك [هـ ٢١ظ] الدائرة، وقطب الثالثة مسامت لقطب الأولى. وقطب الثانية بحيث يكون بعده عن قطب الأولى نصف غاية الميل، وكذا عن قطب التدوير.

[١٩] فنفرض أولا هذا شماليا عن قطب الثانية، وكذا هو عن قطب الأولى. ومركز التدوير [ب ٢١٣و] فيما بين الذنب والرأس.[٣] فتتحرك

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[١] أحدهما: أحديهما [ج]

[٢] غيرهما: +«أحديهما»، قبلها، ثم شطبت [ج]

[٣] الرأس: +«كان المائل»، بعدها، ثم شطبت [ب]

the cincture of the ecliptic were determined, such that whenever the center of the epicycle (falls) on one of them, while the planet (falls) at either the (epicyclic) apogee or perigee, it (the planet) has no latitude. (On the other hand), when the center of the epicycle (falls) on any other point between the (above) two, while the planet (falls) at either the (epicyclic) apogee or perigee, then the inclination of the (epicyclic) apogee is less than the inclination of the perigee. It was thus deduced that the deferent has an inclination away from the cincture of the ecliptic, which is fixed in both the north and the south (directions), and that the two points (mentioned above) are the two nodes.

[17] Indeed, if it (i.e. the center of the epicycle) were at one of the two nodes, then (the planet would fall) in the plane of either the inclined or the parecliptic (orbs). If, however, (the center of the epicycle) crosses them (i.e. the nodes), then the (epicyclic) apogee would incline towards the ecliptic orb, and the perigee (would incline) in the opposite (direction). Had this not been (the case), the distance of the (epicyclic) apogee away from it (i.e. from the ecliptic) would not always be smaller than the distance of the perigee.

[18] [f. 36v] The author of the *Tadhkira* posits for the second inclination three spheres which encompass the epicycle, such that their center is its (i.e. the epicycle's) center. (Moreover), the cincture of the first one (of the above spheres) is in the plane of the cincture of the inclined (orb). We draw a circle which passes through the two poles of the epicycle, (such that) the pole of the first (sphere falls) on this circle, while the pole of the third is immediately above the pole of the first. The pole of the second (sphere) is such that its distance from the pole of the first is equal to half the maximum value of the inclination, and so is (its distance) from the pole of the epicycle.

[19] We first assume this (pole of the epicycle) to be north of the pole of the second (sphere), and similarly (we assume) this (latter pole to be north) of the pole of the first (sphere). (Let) the center of the epicycle (fall) between the head and the tail. The first (sphere) moves

الأولى مثل الحامل، والثانية ضعفه في خلاف جهة الأولى. والثالثة مثل الأولى وفي جهته. فيتحرك قطب التدوير على الخط المستقيم، وكذا كل جزء من أجزائه حتى الذروة.

[٢٠] [أ ٣٧و، ج ٣٣و، ف ٢٨٥ظ، خ ٣٦و] وإن فرضنا قطب الأولى في سطح منطقة المائل، لتقرب ذروة التدوير منه، فتنطبق عليه، ثم تبعد، يحصل المقصود.

[٢١] [ب ٢١٣ظ، ج ٣٣ظ] وصاحب التحفة جعل الميل الثاني ثابتا أيضا، بإثبات كرة أخرى سماها المميلة.[١] فأثبت في ثخن الخارج كرة سماها محيطة، حركتها مثل الخارج، أعلاها إلى التوالي، لأجل التشابه، ثم في جوفها مميلة، بعد مركزها عن مركز المحيطة مثل بعد مركز الخارج عن مركز العالم. وحركتها ضعف المحيطة، إلى خلاف جهتها. ثم في جوفها التدوير، مركزها مركزه. حركته مثل حركة المحيطة [هـ ٢٢و] مع الخاصة، أعلاه إلى التوالي.

[٢٢] ومنطقتا التدوير والمميلة[٢] [ف ٢٨٦و] تتقاطعان. وخط [خ ٣٦ظ] أ ب هو الفصل المشترك بينهما. ونقطة جـ منتصف ما بين أ ب من منطقة المميلة،[٣] ونقطة د منتصف ما بين ب أ. فكل نصف من

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[١] المميلة: الممثلة [ج]

[٢] المميلة: الممثلة [ج، ف]

[٣] المميلة: الممثلة [ج]

like the deferent, while the second moves twice (as fast) and in a direction opposite to that of the first. The third (sphere) moves like the first one, and in the same direction. The pole of the epicycle thus moves on the straight line, and so does each one of its parts, including the (epicyclic) apogee.

[20] [f. 37r] If, (on the other hand), we assume that the pole of the first (sphere falls) in the plane of the cincture of the inclined (orb), such that the epicyclic apogee approaches it until it coincides with it, and then it moves away (from it), then the required (still) obtains.

[21] The author of the *Tuḥfa* makes the (value of the) second inclination fixed as well, by positing another sphere which he calls the inclining (sphere). To account for uniformity, he posits a sphere in the thickness of the deferent, which he calls an encompassing (sphere), such that its motion is like that of the deferent, and its upper part (moves) in the direction of the sequence (of the signs). (He) then (posits) an inclining (sphere) inside it (i.e. inside the encompassing sphere), such that the distance between its center and the center of the encompassing (sphere) is equal to the distance between the center of the deferent and the center of the world. Its motion is twice as much as the (motion of) the encompassing (sphere), and in the opposite direction. The epicycle (is also posited) inside (the inclining sphere), such that their centers are the same. Its motion is equal to the motion of the encompassing (sphere) plus the (motion in) anomaly, (such that) its upper part (moves) in the (direction of the sequence of the signs.

[22] The cinctures of the epicycle and the inclining (sphere) intersect. (Let) line *AB* be the intersection (line) which is common to both of them. (Let) point *G* (fall) midway between *A* and *B*, on the cincture of the inclining (sphere), and point *D* midway between *B* and *A*. Thus the half of

منطقة التدوير مع أ جـ ب يكون شماليا عن الميلة، وكل[١] نصف مع ب د أ جنوبيا عنها. غاية /البعد بينهما بقدر الميل الثاني. [أ ٣٧ظ] ومنطقة الميلة في سطح المائل.

[٢٣] ففرضنا أولا مركز التدوير فيما بين[٢] العقدتين، عند منتصف النصف الجنوبي، والذروة في غاية الميل الشمالي عن جـ. فهي بين المائل والمنطقة. فإذا تحرك الحامل ربع دور، وصل مركز التدوير إلى إحدى العقدتين. وتحرك أيضا الميلة ربع الدور. فخط أب انطبق على الفصل المشترك بين الممثل والمائل، فصار نقطة ب أبعد نقطة[٣] من منطقة التدوير عن مركز العالم. فصار ذروة، وقطر الصباحي والمسائي، صار في سطح الممثل، بأن تكون زاوية تقاطع منطقة المائل والممثل، كزاوية تقاطع منطقة التدوير والميلة.[٤]

[٢٤] فإذا فارق مركز التدوير العقدة وقع في النصف الشمالي عن الممثل. ثم إذا قطع ربع الدور، والميلة[٥] أيضا قطعت الربع، صار نقطة د من الميلة[٦] أبعد نقطة[٧] من مركز العالم. معها من منطقة التدوير،

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[١] وكل: فكل [ب]

[٢] /البعد...بين: العبارة، سقطت [ب]

[٣] نقطة: نقط [أ]

[٤] الميلة: المثلة [ج]

[٥] الميلة: المثلة [ج]

[٦] الميلة: المثل [ب]

[٧] نقطة: نقط [أ]

the epicyclic cincture which falls with *AGB* (on one side) is north of the inclining (sphere), whereas the half which (falls) with *BDA* (on the other side) is south of it. The maximum (value of the) distance between them (i.e. the cincture of the inclining sphere and the epicycle) equals the value of the second inclination.[f. 37v] The cincture of the inclining (sphere of the above model falls) in the plane of the inclined orb.

[23] We first assume that the center of the epicycle falls between the two nodes, at the middle of the southern half, while the epicyclic apogee is at its maximum southerly inclination away from *G*. It (i.e. the epicyclic apogee) is thus (located) between the inclined (orb) and the cincture (of the parecliptic). If the deferent then moves through a quarter of a revolution, then the center of the epicycle reaches one of the nodes. The inclining orb also moves through a quarter of a revolution. Line *AB* thus coincides with the intersection (line) which is common between the parecliptic and the inclined (orb), and point *B* becomes the farthest point of the cincture of the epicycle, away from the center of the world. It is thus an epicyclic apogee, and the diameter of the morning and evening (sections of the epicycle falls) in the (plane of the) parecliptic, on the condition that the angle of intersection between the cinctures of the inclined and parecliptic (orbs) be equal to the angle of intersection between the cinctures of the epicyclic and the inclining (orbs).

[24] If the center of the epicycle departs from the node, then it falls on the northern half with respect to the parecliptic. If then it (i.e. the center of the epicycle) moves through a quarter of a revolution, and if the inclining (sphere) also moves through a quarter (of a revolution), then point *D* of (the cincture of) the inclining (sphere) becomes the farthest point from the center of the world. (The point) of the cincture of the epicycle (which falls on the same side) with it (i.e. with point *D*),

وهي الذروة، جنوبي عن د. ونقطة د شمالي عن الممثل. فالذروة بين المائل[1] والممثل. فيكون بهذا الطريق الذروة مائلة إلى جهة الممثل، والحضيض إلى خلاف جهته.

[٢٥] [ب ٢١٤و] واعلم أن قطر[2] الصباح والمساء ليس في سطح المائل، [ج ٣٤و] بل في سطح الممثل، أو سطح دائرة موازية له.

[٢٦] [أ ٣٨و، ف ٢٨٦ظ، خ ٣٧و] وطريقة التذكرة لم تفد الانتقال من الموازاة إلى الانطباق، ثم منه إليها.

[٢٧] [هـ ٢٢ظ] وطريقة [ف ٢٨٧و] التحفة تنافي الموازاة،[3] لأنه جعل ذلك القطر في سطح المائل. فلا يكون موازيا لمنطقة الممثل على ما مر من اختلاف [خ ٣٧ظ] ميل[4] أجزاء المائل. فلا يكون ميل المركز [ب ٢١٤ظ] كميل طرف القطر. ولا يحصل بها الانطباق إلا أن تكون زاوية [ج ٣٤ظ] تقاطع منطقتي الميلة والتدوير كزاوية تقاطع المائل والممثل. وليس كذلك، لأن الميل الثاني عند مركز التدوير ليس كالميل الأول.[5]

[٢٨] ويلزم من الطريقتين قطع الأرباع [أ ٣٨ظ] بحسب مركز

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[1] المائل: الكلمة، أضيفت في الهامش [أ]

[2] قطر: خط [ف]

[3] الموازاة: +«ذلك أي»، قبلها [ج]

[4] اختلاف ميل: العبارة، أضيفت في الهامش [ب]

[5] الأول: الكلمة، سقطت [أ، ب]

namely the (epicyclic) apogee, is south of *D*. But point *D* is north of the parecliptic. Therefore, the (epicyclic) apogee (falls) between the (cinctures of the) inclined and parecliptic (orbs). By (using) this method, the (epicyclic) apogee inclines in the direction of the parecliptic, and the perigee in the opposite direction.

[25] Take note that the morning and evening diameter does not fall in the plane of the (cincture of the) inclined (orb), rather in the plane of the parecliptic, or in the plane of a circle parallel to it.

[26] [f. 38r] The method of the author of the *Tadhkira* does not produce the transmission from parallelism (between the morning and evening diameter and the plane of the parecliptic) to coincidence, and then back from the latter to the former.

[27] The method of the author of the *Tuḥfa* contradicts the (principle of) parallelism, since he places that (morning and evening) diameter in the plane of the inclined (orb). It (i.e. the diameter) is not parallel to the cincture of the parecliptic, because of the mentioned fact that the (different) points of the inclined (orb) have different inclinations. Thus, the inclination of the center (of the epicycle) will not be equal to the inclination of the end (point) of the diameter. (Furthermore), it (i.e. the method of the author of the *Tuḥfa*) does not produce coincidence, except if the angle of intersection of the cinctures of the inclining (sphere) and the epicycle are equal to the angle of intersection of the inclined and parecliptic (orbs). This is not the case, since the second inclination at the center of the epicycle is different from the first inclination.

[28] The two methods necessitate that the motion through quadratures

الخارج، لا مركز العالم.

[٢٩] فأبدعت طريقا حسنا، وهو أن الميل الأول لا يكون ثابتا. بل يفرض ثلاث كرات لتحريك مركز التدوير شمالا وجنوبا: فمنطقة الحامل تكون في سطح الممثل. ومركز الكبيرة وقطبها على الممثل. وبعد مركز الصغيرة عن مركزها، وقطبها عن قطبها، بقدر نصف غاية الميل الأول. ومركز الحافظة وقطبها في محاذاة مركز الكبيرة وقطبها.

[٣٠] ثم نفرض ثلاث كرات[١] محاطة بتلك[٢] الثلاث،[٣] محيطة بالتدوير، مركزه ومراكزها متحدة. بعدها عن مركز الصغيرة الأولى كما ذكر. وبعد قطب الكبيرة الثانية عن قطب الصغيرة الثانية نصف غاية الميل الثاني وكذا بعد ذروة التدوير عن قطب الصغيرة الثانية. وقطب الحافظة الثانية محاذ لقطب هذه الكبيرة.

[٣١] ثم حركة كل من الكبيرتين كالحامل. وحركة الباقية كما عرفت.

[٣٢] فيوضع أولا مركز الصغيرة الأولى على شمال مركز الكبيرة الأولى، وبقية المراكز على شمال مركز الصغيرة الأولى. ثم الذروة على جنوب قطب الكبيرة الثانية، يتوسط بينهما قطب الصغيرة الثانية. ويوضع قطر الصباح والمساء موازيا لسطح الممثل. فيتحرك المركز على

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[١] كرات: كراة [ج]

[٢] بتلك: لتلك [أ، ب، ج]

[٣] الثلاث: الثلاثة [ب]

[f. 38v] be (measured) with respect to the center of the eccentric, and not (with respect to) the center of the world.

[29] I have devised a good (alternative) method, namely that the first inclination should not be fixed. Three spheres are proposed instead to move the center of the epicycle to the north and to the south: the cincture of the deferent thus falls in the surface of the parecliptic. The center of the large (sphere) and its pole (also fall) in the (surface of the) parecliptic. The distance of the center of the small (sphere), from its center (i.e. that of the large sphere), and the distance between their poles, is equal to half the maximum value of the first inclination. The center of the retainer (sphere) and its pole are aligned with the center of the large (sphere) and its pole.

[30] We next assume three spheres encompassed by the (above) three, (such that) they encompass the epicycle, and their centers coincide. The distance between them (i.e. these centers) and the center of the first small circle is as mentioned above. The distance between the pole of the second large (sphere) and the pole of the second small (sphere) is equal to half the maximum value of the second inclination, and so is the distance between the epicyclic apogee and the pole of the second small (sphere). The pole of the second retainer (sphere) is aligned with the pole of this (latter) large (sphere).

[31] Next, the motion of each of the two large (spheres) is equal to that of the deferent. The motion of the rest of them (i.e. the spheres) is as (already) introduced.

[32] First, we place the center of the first small (sphere) north of the center of the first large (sphere), while the rest of the centers are placed north of the center of the first small (sphere). The (epicyclic) apogee is south of the pole of the second large (sphere), and the pole of the second small (sphere) falls halfway between them. (Next), the morning and evening diameter is placed parallel to the plane of the parecliptic. The center (of the epicycle) thus moves along

خط مستقيم، والقطر ينتقل من[1] الموازاة إلى الانطباق، ثم منه اليها. [ب ٢١٥و، ج ٣٥و، ف ٢٨٧ظ، خ ٣٨و] وتتحرك الذروة على خط مستقيم، مخالفة في الجهة لحركة المركز، فيحصل الميل الثاني، بحيث تكون الذروة نحو الممثل.

[٣٣] [أ ٣٩ظ، ب ٢١٥ظ، ج ٣٥ظ، ف ٢٨٨و، هـ ٢٣و، خ ٣٨ظ] وأما إشكال قطع الأرباع فلا نسلم[2] وروده وإدراك ذلك التفاوت.

[٣٤] [ف ٢٨٨ظ، خ ٣٩و] ورصدوا السفليين في الأوج والحضيض والذروة، فوجدوا الزهرة في الأحوال الأربع شمالية، وعطارد جنوبيا. فحكموا بأن الميل غير ثابت كما عرفت.

[٣٥] ثم لم يختلف عرض الكوكب في الذروة والحضيض. /بل شمالي الزهرة كان مقدارا واحدا، وكذا جنوبي عطارد. ووجد غايتهما في الأوج والحضيض.[3] فعرف أن هذا غير مركب. [هـ ٢٣ظ] بل هو غاية أحدهما مع عدم الآخر. ولا يمكن أن يكون غاية الثاني مع عدم الأول، وإلا كان ميل الحضيض أكثر من ميل الذروة. فعلم أنه بالعكس، بأن تكون الذروة والحضيض في سطح المائل. فيكون الأوج والحضيض في

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[1] من: عن [أ، ج]

[2] نسلم: م [ب، ج]

[3] /بل...الحضيض: العبارة، سقطت [ب، هـ]

a straight line, and the diameter moves from parallelism to coincidence, and back from the latter to the former. (Moreover), the (epicyclic) apogee moves along a straight line, in a direction opposite to that of the motion of the center. The second inclination is thus produced, such that the (epicyclic) apogee is (always inclined) towards the parecliptic.

[33] [f. 39v] As for the problem (pertaining to) the motion through quadratures, we do not admit that it arises, nor that the (resulting) discrepancy is perceivable.

[34] (When) they observed the two inferior planets at (deferent) apogee and perigee, and at the (epicyclic) apogee, they found that, during (all) four situations, Venus was (always) north (of the parecliptic), and Mercury south (of it). It was thus deduced that the inclination is not fixed, as was (already) introduced.

[35] Furthermore, the latitude of the planets at (epicyclic) apogee and perigee does not vary. Rather, the northerly (latitude) of Venus has one (fixed) value, and so does the southerly (latitude) of Mercury. (Moreover), the maximum values (of the latitudes of the two planets) are found at the (deferent's) apogee and perigee. It is thus deduced that this (latitude) is not composite. Rather, it is the maximum (value) of one (of the two inclinations coupled) with the absence of the other. It is not possible, (however), that this be the maximum (value) of the second (inclination) with the absence of the first one, for (had this been the case), the inclination of the (epicyclic) perigee would be greater than the inclination of the apogee. It is thus concluded that the opposite holds, (which obtains) if the (epicyclic) apogee and perigee are in the plane of (the cincture of) the inclined (orb). The (deferent's) apogee and perigee are then

منتصف ما بين العقدتين، فتعين[1] موضع العقدتين.

[٣٦] [ج ٣٦و] ووجدوهما[2] في الصباحي والمسائي حين كانا في إحدى العقدتين، وكانا[3] في سطح الممثل. وحين كانا في الأوج أو الحضيض، وجدوا مسائي الزهرة في الأوج إلى الشمال، وفي الحضيض إلى الجنوب. وصباحها بالعكس. [ب ٢١٦و] وفي عطارد على العكس.

[٣٧] [أ ٤٠و] فحكموا بالثالث، متقدما في العقدتين، وفي الغاية فيما بينهما.

[٣٨] فصاحب التذكرة أثبت للعرض الأول ثلاث[4] أفلاك محيطة بالحامل، توجب انطباق منطقة الحامل على منطقة الممثل وانفتاحها. وكيفيتها لا تخفى بعد الإحاطة بما ذكر. ونجعل مركزها مركز العالم، ليكون الانطباقان والغايتان بحسبه.

[٣٩] [ف ٢٨٩و، خ ٣٩ظ] وأثبت لميل[5] الذروة والحضيض ثلاثة أخرى محيطة بالتدوير، كما ذكر في العلوية. وثلاثة أخرى لأجل الانحراف.

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[1] فتعين: فتغير [ب]

[2] وجدوهما: وجدهما [ب]

[3] وكانا: فكانا [ج]

[4] ثلاث: ثلاثة [ج]

[5] لميل: للميل [ج]

halfway between the two nodes, and the position of the nodes is so determined.

[36] The (two inferior planets) are found to be in the morning or evening (portions of the epicycle) when (the centers of their epicycles) are at either one of the two nodes, where they fall in the plane of the parecliptic. If they (i.e. the centers of the epicycles) are at (deferent) apogee or perigee, then the evening (portion of the epicycle) of Venus is north (of the parecliptic), (when the center of the epicycle) is at (deferent) apogee, and to the south at perigee. The opposite (holds in the case of) their morning (portions of the epicycles). The opposite (also holds) in the case of Mercury.

[37] [f. 40r] The third (inclination) is thus deduced, (such that) it is advanced at the two nodes, and at its maximum between them.

[38] (To account) for the first (inclination in) latitude, the author of the *Tadhkira* posits three orbs encompassing the deferent, which entail the (successive) coincidence and opening between the cincture of the deferent and the cincture of the parecliptic. The manner (in which the above three spheres function) is obvious after what was mentioned (above). Their center is taken to be the center of the world, so that the two coincidences and the two maximum (inclinations) are with respect to it.

[39] (To account) for the inclination of the epicyclic apogee and perigee, he (i.e. the author of the *Tadhkira*) posits three more (spheres) surrounding the epicycle, as mentioned above (in the case) of the superior planets. (He also posits) three more (spheres to account) for the deviation (*inḥirāf*).

[٤٠] وأقول لا يمكن الاجتماع بين هذه الثلاثة وتلك الثلاثة، لأن الثلاثة التي لأجل الميل الثاني توجب أن يتحرك قطب التدوير على خط مستقيم، على الدائرة المارة بقطبي التدوير وبالذروة والحضيض، والثلاثة التي لأجل الانحراف توجب أن يتحرك قطب التدوير على الخط المستقيم، (على الدائرة) [1] القاطعة للدائرة الأولى على قوائم. وعجيبا من صاحب التذكرة أنه غفل عن هذا.

[٤١] وأما صاحب التحفة، فإنه رد انطباق المائل وانفتاحه، واختار وجها آخر يحصل منه شماليا مركز التدوير للزهرة، وجنوبيا [2] لعطارد، [ج ٣٦ظ] بأن جعل منطقة الحامل في سطح الممثل، ثم أثبت ثلاث كرات محيطة بالتدوير، مركز الكبيرة شمالي عن الممثل في الزهرة، جنوبي في عطارد. بعده عن الممثل بقدر نصف الميل الأول. ثم بعد [3] [أ ٤٠ظ] مركز الصغيرة [ب ٢١٦ظ] عن مركز الكبيرة نصف ذلك، كبعده عن مركز التدوير. ومركز الحافظة على مركز الكبيرة.

[٤٢] فتتحرك [ف ٢٨٩ظ] الكبيرة ضعف الحامل، لكن حركة رحوية. والصغيرة ضعف ذلك في خلاف جهتها. والحافظة كالكبيرة وفي جهتها.

[٤٣] فيوضع أولا في الزهرة مركز الصغيرة شماليا عن مركز

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[1] (على الدائرة): العبارة، سقطت في كل النسخ وأضيفت للمعنى

[2] جنوبيا: جنوبية [أ، ب، ج]

[3] بعد: الكلمة، تكررت [أ]

[40] I say, (however), that these (latter) three (spheres) and those (former) three cannot be (joined) together, since the three which are (used) to account for the second inclination entail that the pole of the epicycle moves on a straight line, along the circle which passes through the two poles of the epicycle and the epicyclic apogee and perigee, while the three (spheres) which are (used) to account for the deviation necessitate that the pole of the epicycle moves on a straight line, along the circle which intersects the first circle at right angles. It is indeed strange that this (point) escaped the attention of the author of the *Tadhkira*.

[41] As for the author of the *Tuḥfa*, he rejects the (principle of) coincidence and opening of the inclined (orb), and chooses another method through which the resulting center of the epicycle would be northerly, in (the case of) Venus, and southerly, in (the case of) Mercury. He (first) assumes that the cincture of the deferent (falls) in the plane of the parecliptic. He then posits three spheres encompassing the epicycle, (such that) the center of the large (sphere) is north of the parecliptic, in (the case of) Venus, and south of it, in (the case of) Mercury. Its distance (i.e. that of the center of the epicycle) away from the parecliptic is equal to half the first inclination. Next, the distance [f. 40v] of the center of the small (sphere) away from the center of the large one is half the above (distance), which is equal to its distance away from the center of the epicycle. The center of the retainer (sphere falls) on the center of the large one.

[42] The large (sphere) moves twice as fast as the deferent, but its motion is like a millstone. The small (sphere) moves twice as fast (as the large one), and in a direction opposite to it. The retainer (moves as fast) as the large one, and in the same direction.

[43] First, in (the case of Venus) we place the center of the small (sphere) north of the center

الكبيرة، ومركز التدوير شماليا عن مركز الصغيرة. وفي عطارد يوضع جنوبيا. فيتحرك [هـ ٢٤و] مركز التدوير على خط مستقيم. فيبعد عن الممثل بقدر غاية الميل، ثم يصل إليه.

[٤٤] لكن فيه فساد، وهو أنه كما يتحرك المركز عرضا، تتحرك جميع [خ ٢٤و] أجزاء التدوير كذلك، حتى الذروة والحضيض، فيحصل الميل الثاني. وفيه فساد آخر أيضا كما سيأتي.

[٤٥] فنبني الأمر على الانطباق والانفراج، كما هو المشهور بالأفلاك الثلاثة التي ذكرنا. ثم نثبت المميلة، كما في التحفة، بحيث تكون منطقتها في سطح المائل، وما بين منطقتها ومنطقة التدوير مقدار الميل الثاني. فنفرضها أولا عند الأوج. لكن وضع المميلة[١] هنا على عكس ما في العلوية. فأن فيها كان طرفا الفصل المشترك بين التدوير والمميلة[٢] بعدين أوسطين، عند كون التدوير فيما بين العقدتين. وهنا بعد أبعد وأقرب، حينئذ.

[٤٦] فنبين صورته في الزهرة: فنقطة أ البعد الأقرب من المميلة، وهو الحضيض، ونقطة ب البعد الأبعد منها، وهو الذروة، في سطح المائل. فأن الميل الأول هنا في الغاية، والميل الثاني معدوم.[٣] [ف

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[١] المميلة: الممثلة [ج]

[٢] المميلة: الممثلة [ج]

[٣] معدوم: الكلمة، شرح [ف]

of the large one. The center of the epicycle is (also placed) north of the center of the small (sphere). In (the case of) Mercury, the (above centers) are placed south (of each other). The center of the epicycle thus moves along a straight line. It (i.e. the center) moves away from the parecliptic (through) a distance equal to the maximum value of the inclination, and then (the center) arrives back (at the parecliptic).

[44] (The above model), however, has a flaw (*fasād*) in it, namely that all the points of the epicycle, including the epicyclic apogee and perigee, move with the center (of the epicycle) in latitude. The second inclination is thus produced. (The above model) has still another flaw which will be mentioned (below).

[45] (Alternatively), we base (our model) on the (principle of) coincidence and divergence, as is known from (the case of) the three orbs which we have mentioned. We then posit an inclining (orb), as in the *Tuḥfa*, such that its cincture falls in the plane of the inclined (orb), and (the distance) between its cincture and the cincture of the epicycle is equal to the second inclination. We first assume that they (i.e. the centers of the epicycle and the inclining orb fall) at (deferent) apogee. The present position of the inclining orb, however, is opposite to its position in (the case of) the superior planets. In the latter, the two extremities of the intersection (line), which is common to both the epicycle and the (cincture of the) inclining (orb), are (located at) the two mean distances (away from the center of the world), when the epicycle is (halfway) between the two nodes. Here (i.e. in Ṣadr's model), however, (the two extremities are located at) the maximum and minimum distances (away from the center of the world), at the same position (mentioned above).

[46] Let us illustrate the above configuration in (the case of) Venus: (let) point *A* be the closest point of the inclining (orb), which is the epicyclic perigee, and point *B* the farthest point of this (orb), which is the epicyclic apogee. (Both points fall) in the plane of the inclined orb, since, in this (position), the first inclination is maximum, while the second inclination is nonexistent.

٢٩٠و] و د طرفها الشرقي. ويليه[1] من التدوير نقطة و، مائلا إلى الشمال. و جـ طرفها [ج ٣٧و] الغربي، ويليه من التدوير نقطة ه، مائلا إلى الجنوب.[2]

[٤٧] ثم تحرك الحامل ربع الدور حتى وصل مركز التدوير إلى إحدى العقدتين. [أ ٤١و] فتتحرك المميلة ربع الدور،[3] أعلاه إلى خلاف التوالي. فالمسائي الشمالي، وهو و، يصير ذروة شمالية، والصباحي الجنوبي، وهو ه، يصير حضيضا جنوبيا. وخط أ ب، وهو الفصل المشترك، يصير في سطح المائل والممثل، لانطباقهما. فنقطة أ شرقية و ب غربية.

[٤٨] ثم تحرك الحامل ربع الدور، حتى يصل مركز [ب ٢١٧و] التدوير إلى الحضيض. فتتحرك المميلة ربع دور، فتصير نقطة أ [خ ٤٠ظ] ذروة، و ب حضيضا. و جـ صار شرقيا، ويليه ه، وهو الآن مسائي جنوبي. و د صار غربيا، ويليه و، وهو[4] الآن صباحي شمالي.

[٤٩] ثم يتحرك الحامل ربع الدور، حتى يصل إلى العقدة الأخرى. فتتحرك المميلة ربع الدور أيضا. فصار ه، وهو المسائي الجنوبي، ذروة جنوبية. ونقطة و، وهو الصباحي الشمالي، حضيضا شماليا. و أ ب

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[1] يليه: ثلاثة [ج، ف]

[2] الجنوب: الجنوبي [ج]

[3] الدور: +«حتى»، بعدها، ثم شطبت [ج]

[4] وهو: هو [ج]

(Let point) *D* be its eastern extremity (i.e. that of the inclining orb). The point of the epicycle which is adjacent to it is *U*, and it is inclined to the north. (Let point) *G* be its western extremity. The point of the epicycle which is adjacent to it is *E*, and it is inclined to the south.

[47] Next, the deferent moves through a quarter of a revolution, until the center of the epicycle reaches one of the two nodes. [f. 41r] The inclining orb then moves through a quarter of a revolution, (such that) its upper part (moves) in the direction opposite to the sequence of the signs. The evening northerly (extremity), namely (point) *O*, thus becomes a northerly epicyclic apogee, while the morning southerly (extremity), namely (point) *E*, becomes a southerly epicyclic perigee. Line *AB*, which is the common intersection, falls in the plane of the inclined and the parecliptic (orbs), since the two (orbs) coincide. Point *A* is thus westerly, while *B* is easterly.

[48] Next, the deferent moves through a quarter of a revolution, until the center of the epicycle reaches (deferent) perigee. The inclining (orb) then moves through a quarter of a revolution. Point *A* thus becomes an epicyclic apogee, and *B* a perigee. (Moreover, point) *G* becomes easterly, and (point) *E*, which is now an evening southerly (extremity), will be adjacent to it. (Point) *D* becomes westerly, and (point) *U*, which is now a morning northerly (extremity), will be adjacent to it.

[49] Next, the deferent moves through a quarter of a revolution, until it (i.e. the center of the epicycle) reaches the other node. The inclining (orb) also moves through a quarter of a revolution. (Point) *E*, which is the evening southerly (extremity), thus becomes a southerly epicyclic apogee. (Moreover), point *U*, which is the morning northerly (extremity), (becomes) a southerly epicyclic perigee. (Line) *AB*

ينطبق على الممثل والمائل. فنقطة أ غربية، و ب شرقية. ثم يعود إلى الوضع الأول.

[٥٠] فظهر أنه لو لم يوجد الانطباق والانفتاح، كما في التحفة،[١] فالميلة لابد أن تكون في سطح دائرة متوهمة، بعدها عن الممثل بقدر الميل الأول. إذ لو لم تكن منطقتها في سطحها، لا يكون عند الأوج غاية الميل الأول مع عدم الثاني. [ف ٢٩٠ظ، هـ ٢٤ظ] فأن كانت في سطحها، لا يكون الفصل المشترك في سطح الممثل، في العقدتين. [أ ٤١ظ، ج ٣٧ظ، خ ٤١و] وهذا هو الفساد الموعود.

[٥١] وظهر أيضا أن غاية الميل الثاني والثالث بقدر بعد[٢] منطقة التدوير عن منطقة الميلة،[٣] وهذا شيء واحد. فيجب أن يكون الميل الثاني والثالث متساويين. ولكن يمكن أن يقال: نعم، لكن إنما يظهر التفاوت لأن ميل الذروة يرى أقل من ميل البعد الأوسط، لأنها أبعد عن مركز. فما يرى من التفاوت، إن كان بمقدار ما يقتضيه البعد والقرب، فيها. وإن [ب ٢١٧ظ] لم يكن، يمكن أن نفرض منطقة التدوير، بحيث تقرب من منطقة الميلة،[٤] وتبعد عنها، بحسب أرباع الدور، بأثبات ثلاث كرات محاطة بالتدوير كما مرت غير مرة.

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[١] التحفة: +«ذهبت»، قبلها [ب]

[٢] بعد: بقدر [ب]

[٣] الميلة: الممثل [ج]

[٤] الميلة: الممثل [ج]

also coincides with the parecliptic and inclined (orbs). Point *A* will thus be westerly, and *B* easterly. (Finally, the deferent) returns to the first position.

[50] It is evident, therefore, that had there been no coincidence and unfolding, as is (the case) in the *Tuḥfa*, then the inclining (orb) would have to fall in the plane of an imagined circle, whose distance from the parecliptic is equal to the first inclination. (This is so) because if its cincture (i.e. that of the inclining sphere) did not fall in its plane (i.e. that of the imagined circle), then the maximum value of the first inclination, and the nonexistence of the second (inclination), would not be at (deferent) apogee. If, (however), it (i.e. the inclining orb) were to fall in its plane (i.e. that of the imagined circle), then, at the two nodes, the common intersection would not fall in the plane of the parecliptic. [f. 41v] This is the flaw (which we) promised (to mention).

[51] It is also evident that the maximum values of the second and third inclinations are equal to the distance between the cincture of the epicycle and the cincture of the inclining (sphere), and this is one value. Therefore, this entails that the second and third inclinations are equal. It is possible, however, to (respond by) saying that (the above) is true, but the difference only appears because the inclination of the epicyclic apogee appears smaller than the inclination of (the points which are located at) the mean distance, since it (i.e. the inclination of the apogee) is farther away from a center (from which the inclination is measured). Therefore, if (the difference is) equal to the value entailed by the remoteness and closeness (of the extremities of the epicyclic diameter from the center of the world), then the apparent difference is on (account of) it (i.e. this difference). If, (however), it is not, then we can assume the cincture of the epicycle, to be such that it moves closer to the cincture of the inclining (orb), and then moves away from it, as a function of the (motion through) quarters of revolutions. (This, we can do) by positing three spheres encompassed by the epicycle, as was mentioned earlier.

[٥٢] [ف ٢٩١و] ثم اعلم أن رصد الكواكب في الذروة غير ممكن، وكذا السفليين في الحضيض أيضا، لمقارنة[١] الشمس حينئذ. فرصدوا في أواخر زمان الاختفاء وأوائل زمان الظهور. ثم استخرجوا بالحساب أحوال الذروة والحضيض تقريبا. والعلم عند الله.

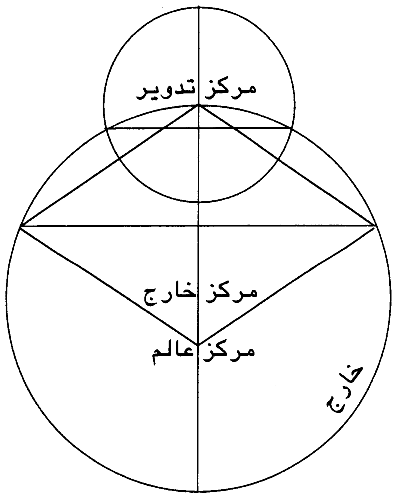
[١] لمقارنة: بمقارنة [أ، ب]

[52] Note also that observation of the planets at (deferent) apogee is not possible, and so is the (observation of the) two inferior planets at the (deferent's) perigee, due to their conjunction with the sun at those instances. Hence, they are observed around the ends of the time of invisibility, and the beginnings of the time of visibility. The approximate conditions are then extracted at (deferent) apogee and perigee by calculation. Knowledge belongs to God.

[١] [خ ٤١ظ] فصل: في النطاقات والاستقامة والرجوع.

[٢] منطقة [ج ٣٨و] الخارج مدار مركز الشمس أو التدوير. ومنطقة التدوير مدار مركز الكوكب، ومركزها مركز هذا [أ ٤٢و] المدار.

[٣] وكل ينقسم أربع نطاقات بخط البعد الأبعد والأقرب، في كل، وبخط البعدين الأوسطين. وهما إما بحسب البعد: ففي الخارج نقطتان يتساوى إليهما الخطان الخارجان من مركزي العالم[١] والتدوير إلى كل منهما. وفي التدوير نقطتا تقاطع منطقتي الحامل والتدوير.



شكل ٤٩

[٤] وإما بحسب السير: ففي الخارج نقطتان ينتهي إليهما خط مار

[١] العالم: +«والخارج»، بعدها [ج]

[1] Chapter [9]: On Sectors, Direct Motion, and Retrograde Motion.

[2] The cincture of the eccentric is the orbit of the center of the sun or of the epicycle. The cincture of the epicycle is the orbit of the center of the planet, and its center is the center of this [f. 42r] orbit.

[3] Each (orbit) is divided into four sectors by means of the line (passing) through the farthest and closest distances, in each (of the above orbits), and by means of the line (passing) through the two mean distances. With respect to distance these are: in the eccenter, the two points, such that the two lines issued from the center of the world and the center of the epicycle to each of them, are equal; In the epicycle, the two points of intersection between the cinctures of the deferent and the epicycle.

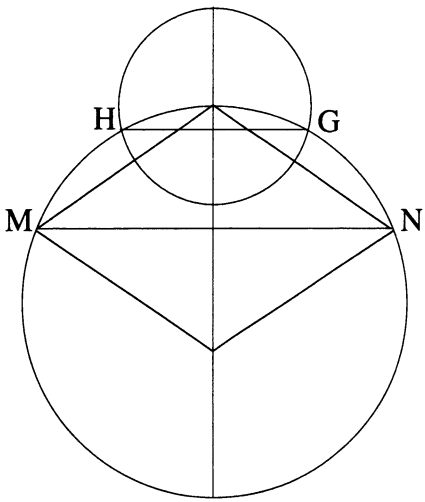
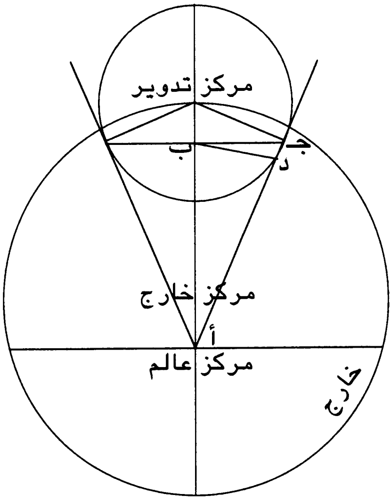


FIGURE 49

[4] With respect to motion they are: in the eccenter the two points, such that the line passing

بمركز العالم، قائم على الخط الأول. وفي التدوير نقطتان يصل إليهما خطان خارجان من مركز العالم إلى محيط التدوير، من غير أن يدخلا في التدوير.



شكل ٥٠

[٥] واعلم أن نقطة تقاطع خط البعدين الأوسطين وخط الذروة والحضيض ليست مركز [ف ٢٩١ظ] التدوير بل تحته. [ب ٢١٨و، هـ ٢٥و] إذ لو كانت مركزا، وفرضناه ب، والبعد الأوسط جـ، ومركز العالم أ، فضلع أ جـ من مثلث أ ب جـ أعظم من أ ب، لأن ذلك وتر الزاوية القائمة.

through the center of the world perpendicular to the first line (i.e. the line passing the farthest and closest distances) ends at them; In the epicycle, the two points on the circumference of the epicycle reached by two lines issued from the center of the world without piercing the epicycle.

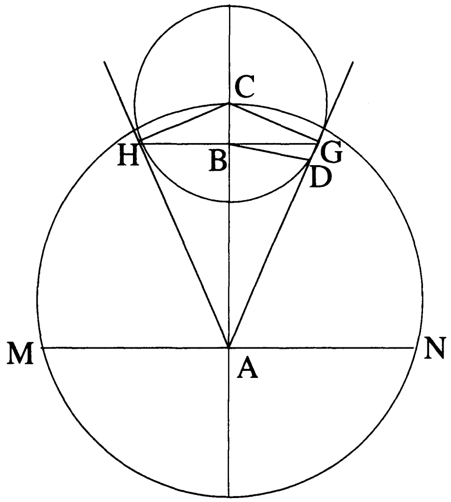


FIGURE 50

[5] Note that the point of intersection of the line (passing) through the two mean distances, and the line (passing) through the apogee and the perigee, is not the center of the epicycle, rather it is (a point) below it (i.e. the center). Let (us assume for the sake of argument that) it be a center. Let this (point) be B [fig. 49], the (point at the) mean distance G, and the center of the world A. Then the side AG of triangle ABG is greater than AB, since the former is the hypotenuse of the right angle.

[٦] فنفصل منه مقدار أ ب، وهو أد.[١] ونصل[٢] ب د. فزاوية أ ب د حادة، لأنها بعض القائمة. فزاوية أ دب حادة أيضا، لكونها مثل الأولى. فزاوية ب د جـ منفرجة. [خ ٤٢و] والضلع الأعظم يوتر الزاوية العظمى، فخط ب جـ أعظم من ب د.

[٧] ولو كان ب مركزا، كان ب جـ نصف قطر. و ب د نصف قطر مع شئ آخر، لأن د خارج عن[٣] محيط التدوير، و جـ يماس محيطه. فيكون ب د أعظم من ب جـ. هذا خلف.

[٨] ثم الكوكب إذا كان في أحد البعدين [ج ٣٨ظ] الأوسطين بحسب السير، لا ترى عند مركز العالم حركته الخاصة، لأن حركته على محاذاة [أ ٤٢ظ] خط يخرج إليه من مركز العالم.

[٩] وفيهما غاية تعديل التدوير. وهي قوس[٤] بين البعد الأوسط وخط الذروة والحضيض، من دائرة مركزها[٥] مركز العالم. ونصف خط البعدين [ف ٢٩٢و] الأوسطين /جيبها.

[١٠] ونصف قطر التدوير قدر بمقدار. وجدت غاية التعديل في الزيجات قوسا جيبها ذلك المقدار. فعلم أن ذلك المقدار هو نصف خط

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[١] أد: أجـ [خ]

[٢] نصل: فصل [ب]

[٣] عن: من [ب]

[٤] قوس: «من»، بعدها، ثم شطبت [أ]

[٥] مركزها: الكلمة، سقطت [أ، ب، ف]

[6] We now mark on it (i.e. on *AG*) an amount (equal to the length) of *AB*. Let this be *AD*. We then join *BD*. Angle *ABD* is acute, since it is (only) a portion of the right angle. Thus, angle *ADB* is also acute, since it is equal to the first one. Therefore, angle *BDG* is obtuse. And since the biggest side is the chord of the biggest angle, therefore line *BG* is greater than line *BD*.

[7] Now, had *B* been the center, then *BG* would be a radius. *BD* would then be a radius plus something else, since *D* (falls) outside the circumference of the epicycle, while *G* is (its point of intersection with the line which is) tangent to it. Therefore, *BD* would be greater than *BG*. This is a contradiction.

[8] Next, if the planet is at either one of the two mean distances (which are determined) with respect to motion, then its anomalistic motion is not visible at the center of the world, because its motion is directly above [f. 42v] a line which is issued to it (i.e. to the planet) from the center of the world.

[9] The maximum epicyclic equation is at these two points (i.e. the mean distances). This is an arc between the mean distance and the line (passing) through the apogee and the perigee, (such that this arc is measured) on a circle whose center is the center of the world. Its sine (i.e. that of the above equation) is (equal to the length of) half the line (passing) through the mean distances.

[10] The radius of the epicycle is estimated to be a certain amount. The maximum equation in the *zījes* is then found to be an arc whose sine is that amount. It is thus deduced that the above length is (equal to) half the line (passing)

البعدين[١] الأوسطين. /وهو في الحقيقة ليس نصف قطر التدوير،[٢] بل أقل، لأن ذلك الخط لم يمر بالمركز. لكن زاويته أعظم من زاوية نصف قطره، [ب ٢١٨ظ، خ ٤٢ظ] /لاسيما في المريخ والزهرة. [هـ ٢٥ظ]

[١١] وإن سمي[٣] نصف قطر[٤] التدوير، فلا مشاحة في الاصطلاح. لكن يلزم منه خلل[٥] في الأعمال، لأن خط الذروة والحضيض [أ ٤٣و، ف ٢٩٢ظ] قطر حقيقي، فنصف قطر التدوير لا يكون مقدارا واحدا.

[١٢] [ب ٢١٩و، ج ٣٩و، ف ٢٩٣و، خ ٤٣و] ولم يريدوا بنصف قطر التدوير حقيقته، بأن يكون قاعدة مثلث متساوي الساقين المخرجين من مركز العالم، أحدهما إلى مركز التدوير والآخر إلى محيطه. لأن الخط الآخر لا يصل إلى البعد الأوسط، لا سيما في المريخ والزهرة، فإن ذلك الخط أعظم بكثير من الخط الواصل إلى البعد الأوسط، لأن ذلك الخط مساو لنصف قطر المائل، وهو ستون، وخط البعد الأوسط استخرجته بالحساب في الزهرة فكان مو[٦] تقريبا. [أ ٤٣ظ، ج ٣٩ظ، ف

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[١] /جيبها...الأوسطين: العبارة، في الهامش [ف]

[٢] /وهو...التدوير: العبارة، في الهامش [ب]

[٣] /لا...سمي: العبارة، شرح [ج]؛ وإن سمي: العبارة، شرح [ف]

[٤] قطر: الكلمة، سقطت [أ، ب]

[٥] خلل: طل [أ، ب]

[٦] مو: مز [ج]

through the mean distances. In reality, (however), (this latter line) is not (equal to) the radius of the epicycle, rather it is smaller, since it does not pass through the center (of the epicycle). Its angle (i.e. the angle subtending half the line passing through the mean distances) is, however, greater than the angle of its radius (i.e. the angle subtending the radius of the epicycle), especially in (the cases of) Mars and Venus.

[11] If it is named half (the diameter) of the epicycle, then the dispute is not over the convention. However, a defect in calculation results from it, because the line (passing) through the apogee and perigee [f. 43r] is a real diameter, which means that the radius of the epicycle does not have one value.

[12] (Moreover), the radius of the epicycle is not understood to mean the real one, namely the base of an isosceles triangle, whose two equal sides are issued from the center of the world, (such that) one of them (reaches) to the center of the epicycle, and the other one to its circumference. (The above is true) because the latter line does not reach the mean distance, especially in (the cases of) Mars and Venus. The former line is indeed much larger than the line which reaches the mean distance, since the (first) line is equal to the radius of the inclined orb, that is sixty (parts), while the mean distance line, which I extracted by calculation for Venus, is approximately 45 (parts).

٢٩٣ظ، هـ ٢٦و]

[١٣] ثم خط البعدين الأوسطين فاصل بين أعلى التدوير وأسفله، المختلفين في جهة الحركتين. ففي القمر حركة الأسفل إلى التوالي. فحركة القمر سريعة بالنسبة إلى مجرد حركة الحامل. غاية سرعته [خ ٤٣ظ] في الحضيض المرئي، لأن حركة الخاصة ترى أسرع، لأن وتر قوس الحركة قائم على الخط الواصل من مركز العالم إلى الكوكب.

[١٤] والأعلى على[١] خلافه، فالحركة بطيئة غاية البطء عند الذروة، لما مر.

[١٥] وفي المتحيرة على [أ ٤٤و، ب ٢١٩ظ] العكس. [ف ٢٩٤و] ويرجع في أسفله. فلنبين سببه. فاعلم أنه إذا أخرج خط من مركز الحامل إلى الكوكب، بحيث يكون بعضه وتر القوس من منطقة التدوير، فنسبة الخاصة إلى حركة الحامل: إما كنسبة ما بين مركز الحامل إلى الكوكب، من ذلك الخط، إلى نصف ذلك الوتر، فالكوكب واقف؛ أو أصغر، فبطيء؛ أو أعظم، فراجع، سواء كان الوتر قطراً أو لا.

[١٦] أما إذا كان قطرا، بأن يكون الكوكب في الذروة أو[٢] الحضيض، [ج ٤٠و، خ ٤٤و] فنفرض أ مركز[٣] التدوير. و أ ب نصف قطره، وكذا أ جـ. ونحرك الكوكب جزءاً واحدا من التدوير، وهو قوس

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[١] على: الكلمة، غير واضحة [ج]

[٢] أو: و [ج]

[٣] مركز: +«من»، بعدها [ج]

[13] [f. 43v] Moreover, the line (passing) through the two mean distances separates the upper and lower parts of the epicycle, whose directions of motion are different. In the (case of the) moon, the motion of the lower part (of the epicycle) is in the direction of the sequence of the signs. The motion of the moon is thus fast with respect to the motion of the deferent alone. Its maximum speed is at the true epicyclic perigee, where the anomalistic motion appears faster because the chord of the arc of motion is perpendicular to the line which joins the center of the world and the planet.

[14] (In) the upper part (of the epicycle the situation) is in the reverse. There the motion is slowest, because of what was mentioned (above).

[15] In (the case of) the wandering planets, [f. 44r] the opposite holds. It (i.e. the planet) is retrograde in its (i.e. the epicycle's) lower part. So let us explain the cause for this (retrograde motion). Note that if a line is issued from the center of the deferent to the planet such that a part of it is the chord of the arc of the cincture of the epicycle, then the ratio of the (motion in) anomaly to the motion of the deferent is: (1) either equal to the ratio (of the section) of that line, which is between the center of the deferent and the planet, to one half of that chord, where the planet is stationary; or (2) smaller (than that ratio), where it (i.e. the planet) is slow; or (3) greater (than that ratio), where it (i.e. the planet) retrogrades. (The above is true) irrespective of whether or not the chord is a diameter.

[16] (First, let us consider) the case when it (i.e. the above chord) is a diameter, that is when the planet is at either the (epicyclic) apogee or perigee. Let point *A* [fig. 52] be the center of the epicycle. *AB* is its radius, and so is *AG*. Let the planet move through one degree along the epicycle, that being an arc

وتره ب جـ. ثم نفرض د مركز الحامل، و د ه خطا واصلا من مركز الحامل إلى الكوكب عند الحضيض مثلا. وخط دز[١] يساوي ده. على أن زاوية د مثل زاوية أ، و دز ضعف أ ب،[٢] /و دز ضعف أ جـ.[٣] فجميع زوايا هذا المثلث مساوية لجميع زوايا ذلك، للشكل السادس من المقالة السادسة. [ب ٢٢٠و] وإذا تساوت الزوايا، [ف ٢٩٤ظ] تناسبت الأضلاع، للشكل الثالث.[٤] ب جـ نصف قاعدة ه ز. فجزء من منطقة التدوير مساو لنصف جزء من الدائرة التي د ه نصف قطرها. وهذه الدائرة تتحرك بحركة الحامل. فلا بد أن يتحرك [أ ٤٤ظ] التدوير [هـ ٢٦ظ] جزءين على خلاف جهة الحامل، ليكون مساويا لجزء من تلك الدائرة، ليرى الكوكب واقفا.[٥] وإذا زاد حركة التدوير على جزئين يرى راجعا. وإن نقص كان بطيئا.

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[١] دز: د [ج]

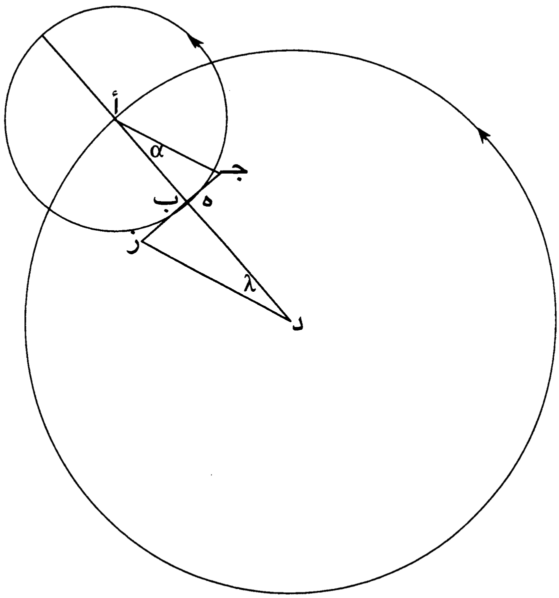
[٢] أ ب: أد [ب]

[٣] /و دز...أ جـ: العبارة، سقطت [ب]

[٤] الثالث: الثاني [هـ]

[٥] واقفا: راجعا [أ، ب، ج]

whose chord is *BG*. Also, let *D* be the center of the deferent, and *DE* be a line which joins the center of the deferent and the planet, (when the latter falls) at the epicyclic perigee, for example. Let lines *DZ* and *DE* be equal, such that angles *D* and *A* are equal, *DZ* is double *AB*, and *DZ* double *AG*. Then, according to the sixth figure of the sixth book (of Euclid's Elements), all the (corresponding) angles of these two triangles (i.e. triangles *DEZ*, and *ABG*) are equal. Once the angles are equal, then according to the third figure (of the same book), the sides are proportional, and *BG* is half the base *EZ*. A degree on the cincture of the epicycle is thus equal to half a degree on the circle whose radius is *DE*. This circle moves with the motion of the deferent. Therefore, the epicycle should move [f. 44v] two degrees in the direction opposite to the deferent, so that it (i.e. motion of the epicycle) is equivalent to one degree on that circle (i.e. the deferent), and so that the planet appears to retrograde. If the motion of the epicycle increases beyond two parts, then (the planet) appears to retrograde. If it decreases, then (the planet appears to be) slow.



شكل ٥٢

[١٧] أقول: هذا الحكم تقريبي، لا تحقيقي. لأنه إذا كان الكوكب في حضيض التدوير، كان بهذه الصورة (شكل ٥٣). وفرضنا أنه تحرك مقدار [ج ٤٠ظ] قوس وترها ب جـ. فخط أ ب نصف قطر التدوير. وكذا أ جـ. و دب[١] هو الخط الواصل، وكذا د جـ وكل منهما ضعف لخط أب، وخط أجـ. فنصفنا د ب على نقطة س، و د جـ على [خ ٤٤ظ] ع. فلو كان جزءان من التدوير يساوي[٢] جزءاً من تلك الدائرة، /كان زاوية

[١] د ب: د يب [ج]
[٢] يساوي: ساوى [ج]

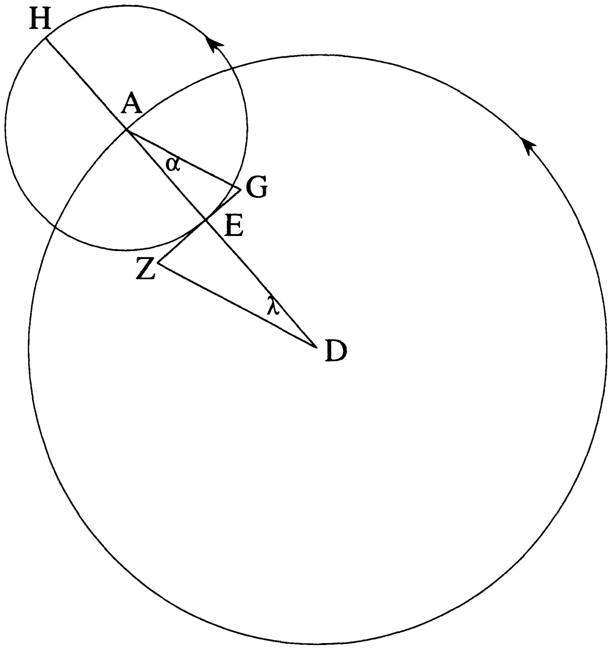
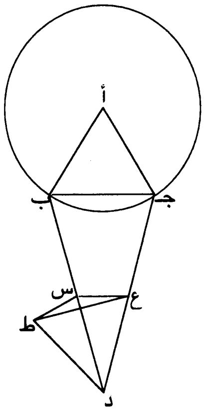


FIGURE 52

[17] I say, however, that this rule is approximate, and not precise. Because, if the planet is at the epicyclic apogee, it is as in the following figure (see fig. 53). Let it (i.e. the planet) move through the length of an arc whose chord is *BG*. Line *AB* (in this figure) is the radius of the epicycle, and so is *AG*. *DB* is the line which joins (the center of the deferent and the planet), as is *DG*. Each of these two (lines) is double the line *AB*, or the line *AG*. We then bisect *DB* at point *S*, and *DG* at *O*. Now had two degrees on the epicycle been equivalent to one degree on that circle (i.e. the deferent), then angle

أ ضعف زاوية د. وهذا محال،[١] لأنها لو كانت ضعفها، تحدث زاوية أخرى من نقطة د مساوية للزاوية الأولى، بأخراج خط آخر، وهو خط دط،[٢] ومساويا لخط د ع ولخط د س. ونصل ط ع، وكذا نصل ط س. وقد كان س ع نصف ب جـ، وخط ط س مساو لخط س ع فمجموعهما[٣] يساوي خط ب جـ. /ثم د ط يساوي أ ب، و دع يساوي أ جـ، وزاوية ط د ع مساوية لزاوية أ، فخط ط ع يساوي خط ب جـ.[٤] فخط ط ع مساو لخطي ط س، س ع.[٥] هذا خلف.



شكل ٥٣

[١] محال: مح [ج]

[٢] دط: دما [ج]

[٣] فمجموعهما: لجموعهما [ج]

[٤] /ثم...ب جـ: العبارة، سقطت [ب]

[٥] /كان...س ع: العبارة، شرح [ج]

A would have been double angle *D*. This is impossible, because if (the first) angle were double (the second), then one should be able to produce another angle at point *D*, which is equal to the first one, by (simply) issuing another line, namely line *DT*, (such that it is) equal to lines *DO* or *DS*. We then join *TO* and *TS*. *SO* would thus be half *BG*, and line *TS* would be equal to line *SO*. Their sum would then be equal to line *BG*. *DT* would also be equal to *AB*, and *DO* equal to *AG*. (Moreover), angle *TDO* equals angle *A*. Therefore, line *TO* equals line *BG*, and line *TO* would be equal to (the sum of) the two lines *TS*, and *SO*. This, (however), is impossible.

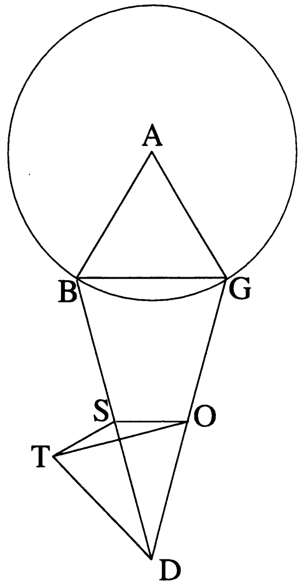


FIGURE 53

[١٨] فكأنهم [ف ٢٩٥و] إنما اعتبروا هذا الحكم التقريبي، لأن كلا من الذروة والحضيض ليس له امتداد يحس فيه ما ذكرنا من التفاوت.

[١٩] ثم ما ذكروا يوجب الجزء الذي لا يتجزأ، لأن موضع الوقوف لا يمكن أن يفرض بحيث يكون له امتداد.[١] [أ ٤٥و] إذ[٢] لو كان، فبعض[٣] أجزائه أقرب إلى مركز الحامل. فالخطوط[٤] المخرجة منه إلى تلك الأجزاء بعضها أقصر وبعضها أطول، فلا تكون نسبتها إلى نصف قطر التدوير كنسبة الحركة إلى الحركة.

[٢٠] [ب ٢٢٠ظ] وأما إذا لم يكن الوتر قطرا، بأن يكون الكوكب في غير الذروة والحضيض، فأن وتر قوس الحركة غير قائم على الخط الواصل، بل مورب،[٥] بخلاف ما إذا كان في أحدهما. كما فرضنا أ مركز الحامل، و ب جـ وتر قوس حركة التدوير، فهو في الرؤية عند أ بمنزلة خط ب ه. على أن أ ب مساو لخط أ ه. فالوتر، وهو خط ب جـ، لو فرض قطر دائرة متحركة، يحركه[٦] التدوير. فأذا [ج ٤١و] قطع

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[١] امتداد: الامتداد [ج]

[٢] إذ: الكلمة، سقطت [ج]

[٣] فبعض: ينقص [ج]

[٤] فالخطوط: والخطوط [ج]

[٥] مورب: يورب [ج]

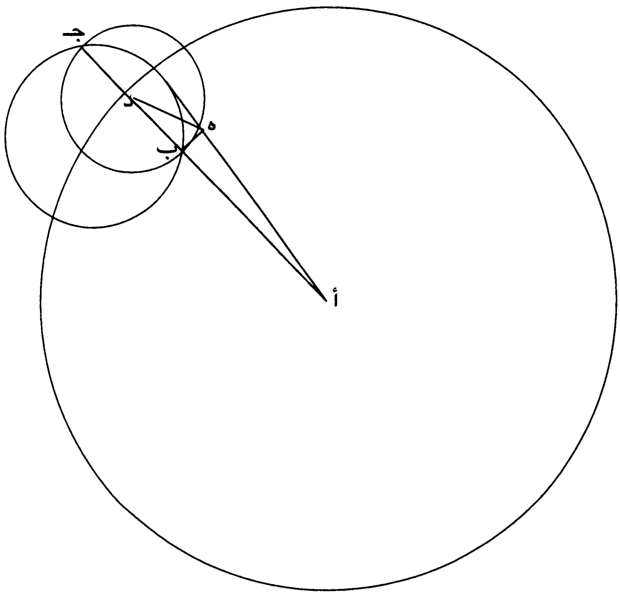
[٦] يحركه: بحركة [خ]

[18] It seems, therefore, that this approximate rule is allowed, only because neither the apogee, nor the perigee has an extension in which the (above-) mentioned difference could be detected.

[19] Moreover, what was mentioned implies the indivisible part, because the stationary position cannot be assumed in such a way that it would have an extension, [f. 45r] for if it did, then some of the parts (of that extension) would be closer to the center of the deferent. Some of the lines issued from it (the center of the deferent) to those parts would thus be of shorter or longer (length), and the ratio of these (lines) to the radius of the epicycle would not be equal to the ratio of the (anomalistic) motion to the motion (of the deferent).

[20] If, (on the other hand), it (i.e. the chord of motion) is not a diameter (of the epicycle), which occurs when the planet is at (some point) other than the epicyclic apogee or perigee, then the chord of the arc of motion is not perpendicular to the line joining (the center of the deferent to the planet). Rather, (it is) oblique, in contrast with (the case) when it (i.e. the planet) is at one of the above (two points). We thus assume *A* to be the center of the deferent [fig. 54], and *BG* the chord of the arc of the motion of the epicycle, which has the same appearance as line *BE* when (observed) from *A*, such that *AB* is equal to *AE*. Now, if the chord, which is line *BG*, is assumed to be the diameter of a varying circle, then it is moved by the epicycle. So, if the planet passes

الكوكب بحـركـة التـدوير الخط الموربَ،[1] وهو ب جـ، (بحـيث)[2] يقطع تلك الدائرة عند حضيضها [خ ٤٥و] خط ب ه، فيكون الوتر، وهو ب جـ، هناك بمنزلة القطر إذا كان الكوكب في الذروة أو الحضيض.



شكل ٥٤

[٢١] فرضنا نقطة أ مركز الحامل. وفرضنا أن التدوير قطع قوس ب جـ في اليوم بليلته، فهي في الرؤية[3] عند مركز الحامل ب ه. فنجعل د

[1] المورب: المور [ج]

[2] بحيث: الكلمة، سقطت في جميع النسخ وأضيفت للمعنى

[3] الرؤية: الزاوية [ج]

past the oblique line, that is *BG*, as a result of the motion of the epicycle, such that line *BE* intersects this (latter) circle at its perigee, then the chord, which is (also) *BG*, is equivalent to the diameter (of the epicycle) when the planet is at the epicyclic apogee or perigee.

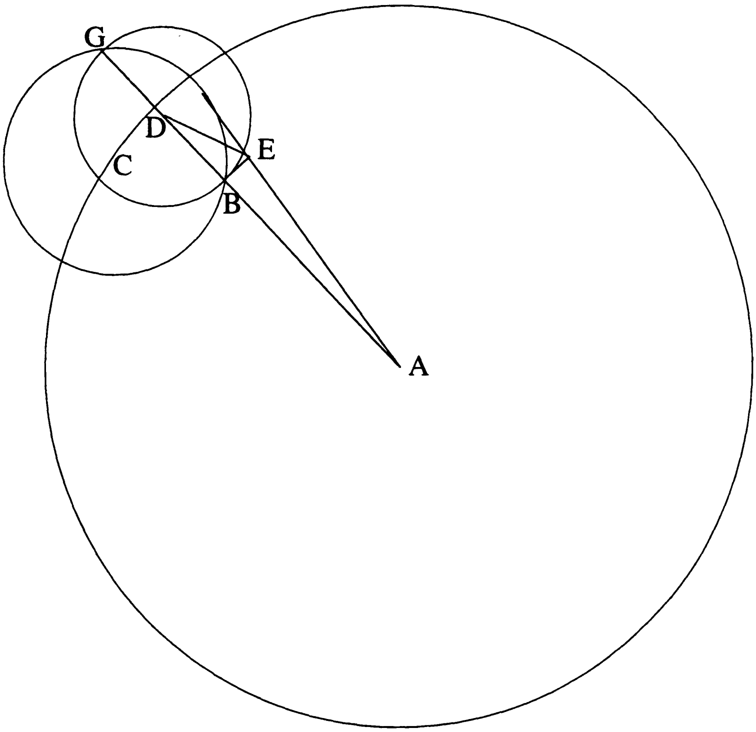


FIGURE 54

[21] Let point *A* be the center of the deferent. Let the epicycle move in one nychthemeron through arc *BG*, which appears as (arc) *BE* at the center of the deferent. We then assume that *D* is

مركزا لدائرة متوهمة يكون ب جـ[١] قطرها. ففي اليوم بليلته قد قطعت تلك الدائرة مقدار ب ه. فعلم[٢] أن خط ب جـ إن لم يكن قطرا للدائرة الكبيرة، فهو قطر[٣] لدائرة صغيرة تكون حركة الكوكب في حضيضها. وزاوية ب ده زاوية حركة الكوكب بالنسبة إلى الدائرة الصغيرة التي هي مرئية عند مركز الحامل. هذه مطالب عسرة المرام في المجسطي، وقد [هـ ٢٧و] بينتها بطرق سهلة المأخذ. إنه المسهل لكل عسير.

[٢٢] و إن[٤] بدل التدوير بالخارج، نخرج إلى منطقته[٥] خطا من مركز الموافق، واصلا إلى الكوكب. ونخرجه في الطرف الآخر، حتى يصير وترا للخارج، سواء يصير قطرا، بأن يكون الكوكب في الأوج أو الحضيض،[٦] [ف ٢٩٥ظ] أو لا يصير قطرا، بأن يكون في غيرهما. ونفرض نصف قطر الخارج ستين، وما بين المركزين عشرة،[٧] وحركة الموافق /ستة أجزاء.

[٢٣] فأن كان نسبة الخارج إلى حركة الموافق[٨] كنسبة ما بين مركز

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[١] ب جـ: ب ه، في جمع النسخ وصححت لاستقامة المعنى

[٢] فعلم: فيجعل فيعلم [ج]

[٣] قطر: قطرا، ثم شطبت الألف [ب، ج]

[٤] وإن: فأن [ج]

[٥] منطقته: منطقة [ج]

[٦] الحضيض: +«في»، قبلها [ج]

[٧] عشرة: عشرين [ج]

[٨] ستة...الموافق: العبارة، سقطت [ج]

the center of an imaginary circle, such that *BG* is its diameter. This circle travels in one nychthemeron through *BE*. It can thus be deduced that if *BG* is not the diameter of the larger circle, then it is the diameter of the small circle, where the motion of the planet is (measured). Angle *BDE* is then the angle of motion of the planet with respect to the small circle which is seen at the center of the deferent. These are inquiries which are hard to attain in the *Almagest*, and I have (just) explained them through methods which can be easily grasped. Indeed, He is the Facilitator of every difficulty.

[22] If the epicycle is replaced by the eccentric, then we extend a line from the center of the concentric to its cincture, such that it reaches the planet. We then extend it (i.e. the line) in the other direction, such that it becomes a chord of the eccentric, irrespective of whether it (i.e. this chord) is a diameter, which is (the case) when the planet is at either the apogee or perigee, or whether it is not a diameter, which is (the case) when it (i.e., the planet) is elsewhere. We then assume that the radius of the eccentric is sixty, and (the distance) between the two centers is ten, and that the motion of the concentric is six degrees.

[23] Now, if the ratio (of the motion) of the eccentric to the motion of the concentric is equal to the ratio of

الموافق والكوكب [أ ٤٥ظ] من ذلك الوتر إلى نصفه، يقف. وإن كانت أصغر أو أعظم، لا ترى إلا حركة الموافق أو الخارج بطيئة.

[٢٤] فالوقوف إن كان عند الحضيض أو الأوج، لا يرى في الفوق أو التحت إلا حركة الموافق أو الخارج. [ب ٢٢١و، ج ٤١ظ، خ ٤٥ظ] وإن كان فيما بينهما، ففيما فوقه تصغر النسبة، وفيما تحته تعظم. [ف ٢٩٦و] فإن كانت الاستقامة من الموافق، والرجوع من الخارج، فهي في الفوق، وهو في التحت. وإن كان بالعكس، فبالعكس. [أ ٤٦و]

[٢٥] فحركة الخارج إن كانت خمسة أو سبعة، فالوقوف في الحضيض أو الأوج. وإن كانت ستة، ففي البعد الأوسط الوقوف، وفيما فوقه أو تحته فما ذكر. [ب ٢٢١ظ، ج ٤٢و، خ ٤٦و، هـ ٢٧ظ] وإن كانت أقل منها وأكثر من الخمسة، أو أكثر[١] منها وأقل من سبعة، فاستخرجه. [ف ٢٩٦ظ]

[٢٦] فأنه إن كانت حركة الخارج أقل من خمسة، لا يرى الوقوف والرجعة، بل يرى حركة فضل حركة[٢] الموافق على الخارج. وإن كانت أكثر من سبعة، لايرى الوقوف [أ ٤٦ظ] والرجعة، بل يرى حركة

---

[١] أو أكثر: فموضع الوقوكثر [ج]

[٢] فضل حركة: العبارة، سقطت [ج]

(the distance) of that chord (measured) between the center of the concentric and the planet [f. 45v] to its half (i.e. half the chord), then it (i.e. the planet) would (appears to) stand still. If it (i.e. the ratio) is either less or greater, then only the motion of the concentric (when the ratio is less), or that of the eccentric (when the ratio is greater) appears to be slow.

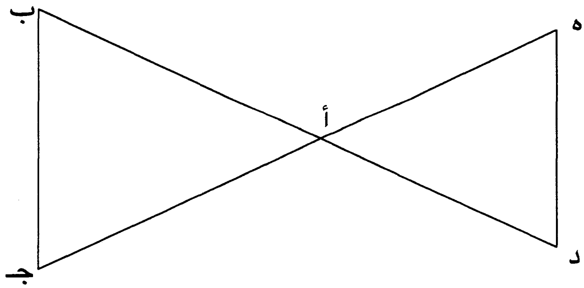
[24] If the stationary point is at either the apogee or the perigee, then only the motion of the concentric in the (part) above (the perigee), or that of the eccentric in the (part) below the apogee, appears (to slow). If, (however), it (i.e. the stationary point) is between the two (i.e. apogee and perigee), then above it (i.e. the stationary point) the ratio (of the motions) decreases (with respect to the ratio of the lines), and below it (i.e. the stationary point) the ratio increases. Thus, if direct motion is with (reference to) the concentric, and if retrograde motion is with (reference to) the eccentric, then the former (i.e. the direct motion) is in the (part) above (the stationary point), and the latter (i.e. the retrograde motion) is in the (part) below. If (the above is) reversed, then the opposite (is true).

[25] [f. 46r] Therefore, if the motion of the eccentric is either five or seven (degrees), then the stationary points are (respectively) at the perigee or the apogee. If it (i.e. the motion) is six (degrees), then the stationary point is at the mean distance, whereas what was mentioned (above applies) when (the planet) is either above or below (this position). If (on the other hand, the motion of the eccentric) is less (than six degrees) and more than five, or more than (six) and less than seven, then (the position of the stationary point can be found) by calculation.

[26] If, however, the motion of the eccentric is less than five (degrees), then no station or retrogradation will be observed, rather what appears is the motion of the concentric less that of the eccentric. If it (i.e. the motion of the eccentric) is more than seven (degrees), then no station [f. 46v] or retrogradation will be observed, rather what appears is the motion

فضل[1] حركة الخارج[2] على الموافق.

[٢٧] [خ ٤٦ظ] /برهانه إذا كان الكوكب في الحضيض الخارج: أنا فرضنا أ مركز الموافق، و أ ب نصف قطره، وهو ستون، وكذا أ جـ. وخط ب جـ وتر قوس الحركة، وهو ستة أجزاء. والخارج يتحرك خمسة أجزاء وترها خط د ه. [ج ٤٢ظ] وبين مركز الموافق والحضيض خمسون. فحصل مثلثان أضلاعهما متناسبة. فزواياهما متساوية، للشكل الخامس من المقالة السادسة من كتاب أقليدس. فزاوية حركة الموافق وحركة الخارج [ب٢٢٢و، ف ٢٩٧و] عند مركز الموافق، متساويتان. فيكون الكوكب واقفا.



شكل ٥٦

[1] حركة فضل: فضل [ب]، وأضيفت الكلمة فوق السطر [أ]

[2] الخارج: +«الموافق على الخارج، وإن كانت أكثر من سبعة لا ترى»، بعدها، ثم شطبت [أ]

of the eccentric less that of the concentric.

[27] The proof (for the above, in the case) when the planet is at the perigee of the eccentric, is (as follows): let *A* [fig. 56] be the center of the concentric, and *AB* be its radius, that being sixty, and so is *AG*. Line *BG* is the chord of the motion, and that is six degrees. The eccentric moves through five degrees, whose chord is line *DE*. (The distance) between the center of the concentric and the perigee is fifty. Two triangles are thus obtained, such that their sides are proportional. Their angles are equal, according to the fifth figure of the sixth book of the book of Euclid. Therefore, the angles of the motions of the concentric and the eccentric (appear to) be equal at the center of the concentric. The planet is then stationary.

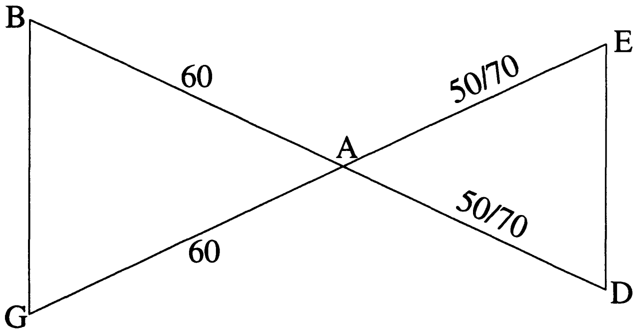


FIGURE 56

[٢٨] فإن زاد حركة الخارج يحصل الرجوع. وإن نقص يحصل البطء.

[٢٩] وأما إذا كان في أوجه، فمثلث أ ب جـ على حاله، ومثلث أده[١] كل من ساقيه سبعون، وقاعدته سبعة. فالزوايا متساوية. فإن زاد حركة الخارج، لا تظهر حركة الموافق، لأن الاستقامة بحركة الخارج، على عكس ما كان في الحضيض. وإن نقص عن[٢] سبعة وزاد على خمسة، يلزم الرجوع.

[٣٠] وإذا كان في غيرهما، فالوتر في حكم القطر، كما مر.

[٣١] وهنا إشكال، وهو أن هذا البرهان يوجب أن يكون موضع الوقوف البعد الأوسط بحسب البعد. وكون نصف الوتر هنا أقل من ستين يوجب أن لا يكون موضع الوقوف هناك.[٣] [أ ٤٧و، ج ٤٣و،ف ٢٩٧ظ، هـ ٢٨و، خ ٤٧و]

[٣٢] والمذكور في كتبهم الرجوع في الحضيض لأنه هو الواقع. والرجوع في الأوج والذروة لما كان ممكنا، ذكرتهما[٤] تتميما للأقسام الممكنة، وتبينا لحال القمر في الذروة.

[٣٣] ثم في التذكرة سوى بين التدوير والخارج، فقال: «ومما يتصل بهذا البحث [ب ٢٢٢ظ] أنا فرضنا لخارج المركز محركا موافق المركز.

[١] أده: أد [ج]

[٢] عن: فمن [ج]

[٣] /برهانه...هناك: العبارة، شرح [ج]

[٤] ذكرتهما: ذكر لهما [ج]

[28] If, (however), the motion of the eccentric increases, then retrograde motion results. Slowness results if it decreases.

[29] Now if it (i.e. the planet) is at its apogee (i.e. that of the eccentric), then triangle *ABG* remains as it was, while each of the two sides of triangle *ADE* are seventy, and its base is seven. The angles are thus equal. (However), if the motion of the eccentric increases, then the motion of the concentric is not apparent, because, in contrast to the situation at the perigee, direct motion (results) from the motion of the eccentric. If it (i.e. the motion of the eccentric) becomes less than seven and greater than five, then retrograde motion is entailed.

[30] If it (i.e. the planet) is at any other (position), then the chord is treated as a diameter, as mentioned above.

[31] A problem, (however), arises in this (case), namely that this proof requires that the position of the station be at the mean distance based on linear measure. The fact that (the length of) half the chord in this (case) is less than sixty thus entails that the station is not in this position.

[32] [f. 47r] What they (i.e. the predecessors) mentioned in their books was the retrograde motion at the perigee, because this is what actually (happens). However, since retrograde motions at the eccentric and epicyclic apogees were (theoretically) possible, I mentioned them in order to complete the possible categories, and to explicate the condition of the moon at epicyclic apogee.

[33] Next, in the *Tadhkira*, he equated the epicycle and the eccentric, saying: "Among the things which are related to this discussion is that we assume the eccentric to have a concentric mover.

وجعلنا نسبة نصف قطر الخارج إلى ما بين المركزين كنسبة نصف قطر الحامل إلى نصف قطر التدوير. وجعلنا موافقي المركز متحركين إلى التوالي حركتين متشابهتين، والخارج المركز إلى خلافه. والتدوير على وجه يكون في البعد الأبعد على التوالي. وحركتاهما أيضا متشابهان ». ثم بعد ذلك ذكر النسبة التي توجب الرجوع ونحوه كما عرفت.

[٣٤] ثم في بعض النسخ رأيت تغييرا في عبارة التذكرة، ونقلا إلى هذه العبارة: «وجعلنا نسبة الخط الواصل بين مركز [خ٤٧ظ] الموافق وحضيض الخارج إلى نصف قطر الخارج كنسبة الخط الواصل بين مركز الموافق وحضيض التدوير إلى نصف قطر التدوير.» [أ ٤٧ظ]

[٣٥] أقول: قد شرط التشابه بين حركتي الخارج والتدوير. فأن أريد بالتشابه [ف ٢٩٨و] المساواة،[١] أي تكون زوايا قسي الحركة متساوية، فالعبارة المنقول إليها صواب، والأولى[٢] خطأ. وإن أريد أنه ترى عند مركز العالم متشابهة، فالعبارة الأولى صواب، لا المنقول إليها. وبعد الوقوف على ماذكرت لا يخفى هذا المعنى. والله أعلم.

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[١] المساواة: المساولة [أ]

[٢] الأولى: الأول [ج]

Let the ratio of the radius of the eccentric to (the distance) between the two centers be equal to the ratio of the radius of the (concentric) deferent to the radius of the epicycle. Let the two concentrics move with two uniform motions in the direction of the sequence of the signs, and the eccentric in the opposite (direction). (Also) let the epicycle be such that it moves in the direction of the sequence of the signs when it is at its farthest distance. The motions of the (last) two (circles, i.e. the eccentric and the epicycle) are also uniform." After this, he (i.e. the author of the *Tadhkira*) mentioned the ratios which entail retrograde motion and the rest (of the motions) as already illustrated.

[34] In some other copies (, however,) I noticed a variant in the wording (of the above quotation) from the *Tadhkira*, and a replacement by the following sentence: "let the ratio of the line joining the center of the concentric and the perigee of the eccentric to the radius of the eccentric be equal to the ratio of the line joining the center of the concentric and the epicyclic perigee to the radius of the epicycle."

[35] [f. 47v] I say (in response): he (i.e. the author of the *Tadhkira*) had postulated as a condition the similarity (*tashābuh*) between the motions of the eccentric and the epicycle. If what was meant by *tashābuh* is equality, that is the arcs of motion should be equal, then the sentence which was substituted would be correct, while the first one would be false. If, (however), what was meant is that they (i.e. the arcs of motion) would appear at the center of the world to be equal, then the first sentence would be correct, and not the altered one. Indeed, after comprehending what I have mentioned (earlier), this concept should be clear. And God knows best.

[١] [أ ٤٨و، ب ٢٢٣و، ج ٤٤و، ف ٢٩٨ظ، هـ ٢٨ظ، خ ٤٨و]
فصل: في اختلاف المنظر.

[٢] وهو لا يحس إلا في القمر. فإذا أخرج خطان من مركز العالم والبصر إلى مركزه، وينتهيان[١] إلى فلك البروج، فموضع الأول موضعه الحقيقي، والثاني المرئي، وهو أقرب إلى الأفق دائما. والقوس الواقعة بينهما من دائرة الارتفاع اختلاف المنظر، والزاوية الحادثة [خ ٤٨ظ] على مركز القمر زاوية اختلاف المنظر.

[٣] وينعدم في سمت الرأس، وغايته عند الأفق. فأن لنصف قطر الأرض مقدارا محسوسا عند فلك القمر، والظاهر منه أقل[ب ٢٢٣ظ] من النصف.

[٤] ويظهر الاختلاف في [ف ٢٩٩و] الطول والعرض: فأن كان الكوكب على دائرة وسط سماء الرؤية، فهو في العرض فقط. [أ ٤٨ظ] وإن كان شرقيا، فالطول المرئي[٢] زائد على الحقيقي، لكون المرئي أقرب إلى الأرض، والتوالي من المغرب إلى المشرق. وإن كان غربيا فناقص.

[٥] وإن كان على المنطقة، فهي إن مرت على سمت الرأس فهو في[٣] الطول فقط. [هـ ٢٩و] و إن لم تمر عليه، فالطول المرئي على ما

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[١] ينتهيان: ينتهيا [ج]

[٢] المرئي: المشرقي [أ، ج]

[٣] في: الكلمة، سقطت [ج]

[1] [f. 48r] Chapter [10]: On Parallax.

[2] It (parallax) is detectable only in the (case of the) moon. Thus, if two lines are issued, (one) from the center of the world and (the other from the point) of vision to its (i.e. the moon's) center, and are extended till the ecliptic orb, then the position (with respect to) the first is the true position, while (that of) the second is the apparent one, which is always closer to the horizon. The arc falling between them (i.e. .the two positions) along the altitude circle is the parallax, while the (corresponding) angle which results at the center of the moon is the angle of parallax.

[3] It (parallax) vanishes at the zenith, and its maximum is at the horizon. (The parallax results) because the radius of the earth has a considerable dimension (with respect) to the orb of the moon, and the visible part of the latter is less than (its) half.

[4] Parallax appears in both longitude and latitude: if the planet (moon) is on the midheaven circle of visibility, then it (i.e. parallax) is only in latitude. [f. 48v] If, (however), it (i.e. the moon) is easterly, then the apparent longitude is greater than the true, because the apparent is closer to the earth, and succession (of the signs) is from the west to the east. If it is westerly, then (the apparent longitude) is less (than the true longitude).

[5] If (the moon) is on the ecliptic, and if the (ecliptic) passes through the zenith (of the observer's locality), then (the parallax) is only in longitude. If, (however, the ecliptic) does not pass through it (i.e. the zenith), then the apparent longitude is as

ذكر.[١] [ج ٤٤ظ] والعرض[٢] المرئي في جهة قطب البروج الخفي.

[٦] وإن لم يكن عليها، /فأن مرت على سمت الرأس، فالطول على ما ذكر.[٣] والعرض المرئي زائد على الحقيقي. [خ ٤٩و]

[٧] وإن لم تمر، فأن كان العرض الحقيقي في جهة قطب البروج الخفي، فكذا. وإن كان في جهة القطب الظاهر، [ف ٢٩٩ظ] /فأن كان بين سمت الرأس والمنطقة، [ب ٢٢٤و] فالمرئي معدوم أو ناقص عن الحقيقي في جهته، أو بقدر فضل الاختلاف على الحقيقي [أ ٤٩و] لكن في خلاف جهته.

[٨] فأن القسم الأول على ثلاثة أوجه: إما أن يكون المرئي مساويا للحقيقي، فيرى الكوكب على المنطقة،[٤] فيكون العرض المرئي معدوما.

[٩] وإما أن يكون المرئي أقل من الحقيقي، فيكون ناقصا عن الحقيقي، ويكون في جهة الحقيقي. كما إذا كان العرض الحقيقي شماليا، وهو درجتان، وهو بين سمت الرأس والمنطقة، والمرئي يكون درجة. فينقص عن الدرجتين،[٥] فيبقى المرئي درجة، ويكون شماليا عن المنطقة، كالحقيقي.

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[١] ذكر: ذكرا، ثم شطبت الألف [أ]

[٢] والعرض: فالعرض [ج]

[٣] /فأن...ذكر: العبارة، شرح [ب]

[٤] المنطقة: الكلمة، سقطت [أ، ب]

[٥] الدرجتين: الأوجين [ب]

mentioned above. The apparent latitude will then be in the direction of the hidden pole of the ecliptic.

[6] If (the moon) is not on it (i.e. the ecliptic), then (there are two cases): (1) (the ecliptic) is either passes through the zenith, in which case the longitude is as mentioned above. The apparent latitude will then be greater than the true one.

[7] (2) Or (the ecliptic) does not pass (through the zenith). Now if the true latitude (of the moon) is on the side of the hidden pole of the ecliptic, then the same (will apply). If, (however), it (i.e. the moon) is on the side of the visible pole, then there are three cases): (1) if (the moon) is between the zenith and the ecliptic, then the apparent (latitude) is either nonexistent, or less than the true altitude and on its side, or equal to the difference between the parallax and the true (latitude) [f. 49r] but on its opposite side.

[8] The first division (of the last three also) has three possibilities: the apparent (latitude) is either equal to the parallax, in which case the planet appears (to fall) on the ecliptic. The apparent latitude will then be nonexistent.

[9] Or the apparent (latitude) is less than the true, in which case it (i.e. the apparent latitude) is less than the true and on the same side. (This is) as (in the case) when the true latitude is northerly, say two degrees, and it falls between the zenith and the ecliptic, while the apparent (position) is one (degree from the true position). It (i.e. the one degree) is subtracted from the two degrees, and the resulting apparent (latitude) is one degree, which, like the true one, will be north of the ecliptic.

[١٠] وإما أن يكون المرئي أكثر من الحقيقي، كما إذا كان الحقيقي درجتين /شماليتين، في جانب سمت الرأس،[١] والمرئي ثلاثا. فالمرئي يكون درجة واحدة، جنوبية عن المنطقة.[٢]

[١١] وإن كان الحقيقي على السمت، فلا اختلاف.

[١٢] وإن [ج ٤٥و] كان لا على السمت، لكن في خلاف جهة المنطقة، فالمرئي زائد على الحقيقي.

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[١] /شماليتين...الرأس: العبارة، سقطت [ب]، أضيفت في الهامش [أ]

[٢] /فأن...المنطقة: العبارة، شرح [ف]

[10] Or the apparent latitude is greater than the true, as (in the case) when the true (latitude) is two northerly degrees, on the side of the zenith, and the apparent position is three (degrees away from the true). The apparent (latitude) will thus be one degree to the south of the ecliptic.

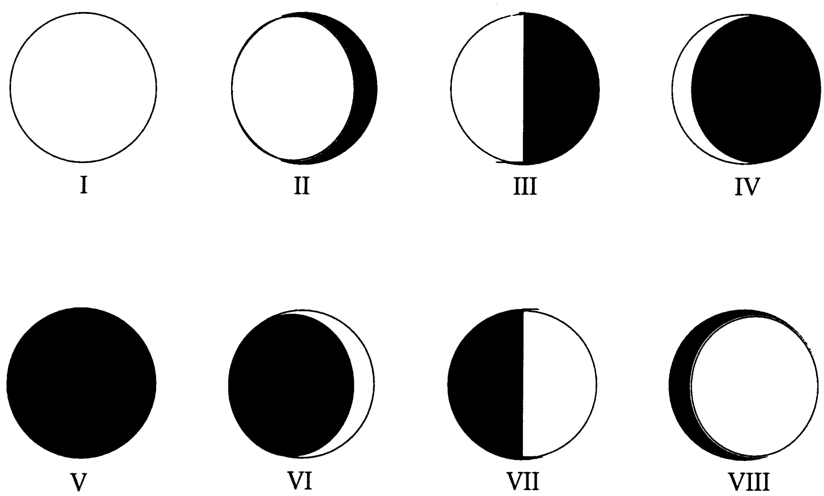
[11] If the true (position) is in the zenith, then there is no parallax.

[12] If it (i.e. the true position) is not on the zenith, but on the side (of the zenith) which is opposite to the ecliptic, then the true (latitude) is greater than the apparent.

[١] فصل: في أحوال النيرين .

[٢] القمر إنما يرى بهذه الأشكال لأن نوره[١] من الشمس، فنصفه تقريبا مضيء، ونصفه تقريبا مواجه لنا.[٢]

[٣] [خ ٤٩ظ، ف ٣٠٠و] فإذا قابل الشمس، يواجهنا المضيء. فنراه كأنه سطح مرآة، مع أنه نصف كرة، لأنه لا يحس قرب بعض الأجزاء وبعده[٣] من البعيد. فترى كل الأجزاء متساوية [هـ ٢٩ظ] في البعد.



شكل ٥٩

[١] نوره: نورها [أ، ب]

[٢] لنا: لها [ف]

[٣] وبعده: بعده [ج]

[1] Chapter [11]: On the Conditions of the Two Luminaries (the Sun and the Moon).

[2] The moon appears to have these (different) forms because its light comes from the sun. Almost half of it is thus luminous, and almost half of it is facing us.

[3] Thus, if it (i.e. the moon) is in opposition to the sun, then the luminous (part of the moon) faces us. It then appears to us as if it were the surface of a (plane) mirror, although it is a hemisphere, because the closeness and remoteness of (its) different parts are not detectable at a great distance. All the points (on the surface of the moon) appear to be equidistant (from a point on the surface of the earth).

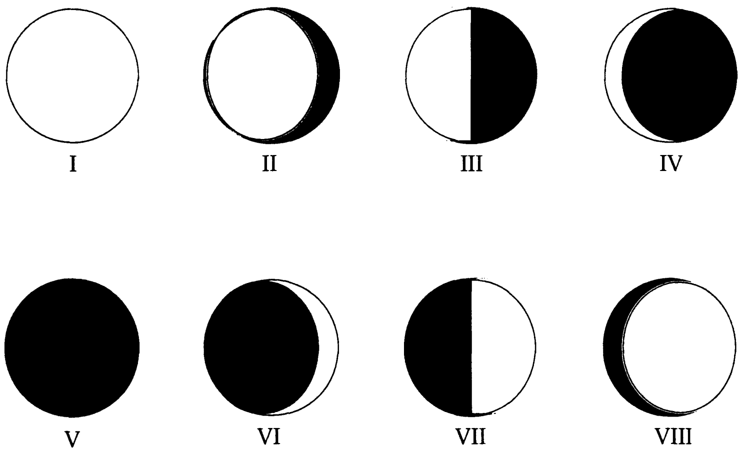


FIGURE 59

[٤] وإذا كان في تربيعها، فنصفه المضيء ينتصف، فيرى كنصف المرآة. [أ ٤٩ظ، ب ٢٢٤ظ] /لأنه يحيط به قوسان، إحداهما[١] من الدائرة الفاصلة بين ما يواجهنا وما لا يواجهنا. وهذه القوس ترى منحنية، كما هي. والأخرى قوس من دائرة فاصلة بين المضيء والمظلم. وهذه القوس ترى خطا مستقيما. لأن كل قوس تكون مع سهمها في محاذاة شعاع البصر كسهمها، لما ذكرنا.[٢]

[٥] أما قبل التربيع، فلأن ما يرى في التربيع نصف مرآة، فهو ينقسم بقسمين: مظلم ومضيء. لكن المظلم يحيط به خطان، أحدهما [ج ٤٥ظ] ذلك الخط المستقيم، والآخر خط[٣] منحن متصل بالمضيء. [خ ٥١و] وبعد التربيع بالعكس.

[٦] [ف ٣٠٠ظ] وعند الاجتماع، النصف المظلم يواجهنا، فلا نراه.

[٧] فإذا وقع في سيره بحيث تحول الأرض [أ ٥٠و] بينه وبين الشمس، فينخسف. وما يرى من[٤] لونه ليس لونه الأصلي، بل ينعكس إليه الضوء الثاني من الأجرام المضيئة من كرة البخار، ولا ينعكس حال المحاق، لأن الضوء الثاني حينئذ على زوايا حادة، كزاوية أ دب،[٥] وفي

[١] إحداهما: أحديهما [أ، ب]

[٢] /لأنه...ذكرنا: العبارة، شرح [أ، ب]

[٣] خط: الكلمة، سقطت [ب]

[٤] من: الكلمة، تكررت [ج]

[٥] أدب: أب جـ [أ، ب]

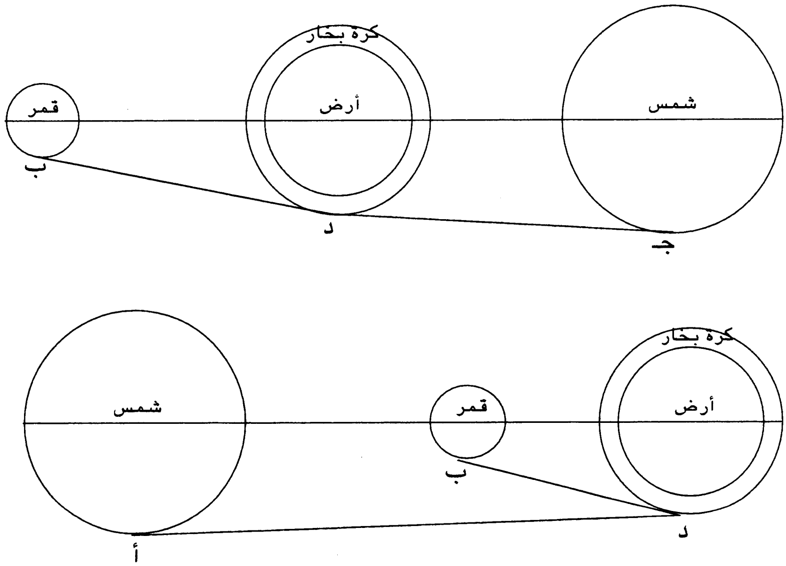
[4] If it (i.e. the moon) is at quadrature from the sun, then its luminous half will be divided, and it will appear as half a (plane) mirror. [f. 49v] (This is so) because it is bounded by two arcs, one of which is (part) of the circle which separates that (part of the moon) which faces us from (the part) which does not face us. This arc appears to be curvilinear, as it actually is. The other one is an arc of the circle which separates the luminous and the dark (parts of the moon). This (latter) arc appears as a straight line, because every arc that falls, together with its versed sine, in the plane of the beam of sight, will appear as this arc, for the above mentioned (reasons).

[5] Before (the first) quadrature, however, the part which appears at quadrature as half a (plane) mirror will be divided into two parts: a luminous (part) and a dark one. This (latter) dark part is bounded by two lines: the first is the above straight line, and the other one is a curved line which is adjacent to the luminous (part). The reverse is (true) after the (first) quadrature.

[6] At conjunction (with the sun), the dark half (of the moon) faces us. Hence we do not see it.

[7] If, during its motion, (the moon) falls (in a position) such that the earth comes [f. 50r] between (the moon) and the sun, then it will be eclipsed. Its apparent color is not its original color, rather a second light (coming) from the luminous celestial bodies is reflected towards it by the sphere of vapor. (This second light) is not reflected during the waning of the moon, because the second light then makes acute angles, like the angle *ADB*, while during

الخسوف على منفرجة كزاوية جـ دب، في هذا الشكل (شكل ٦٠).[١] / والخطان المحيطان بالمنفرجة أشبه[٢] بالخط المستقيم من المحيطين بالحادة. وأقوى الأضواء الواصل من النير على الخط المستقيم.[٣]



شكل ٦٠

[٨] [ب ٢٢٥و، ج ٤٦و، ف ٣٠١و، هـ ٣٠و، خ ٥٠ظ] وظل

[١] شكل ٦٠: الشكل، سقط [ج]

[٢] /والخطان...أشبه: العبارة، تكررت [ج]

[٣] /والخطان...المستقيم: العبارة، شرح [ج]

eclipse it (makes) an obtuse one, like angle *GDB* in the following diagram (see fig. 60). (Moreover), the two lines subtending an obtuse (angle) resemble a straight line more than the two subtending an acute (angle) do. (Furthermore), the strongest light is the one which arrives from the luminary (the sun) along a straight line.

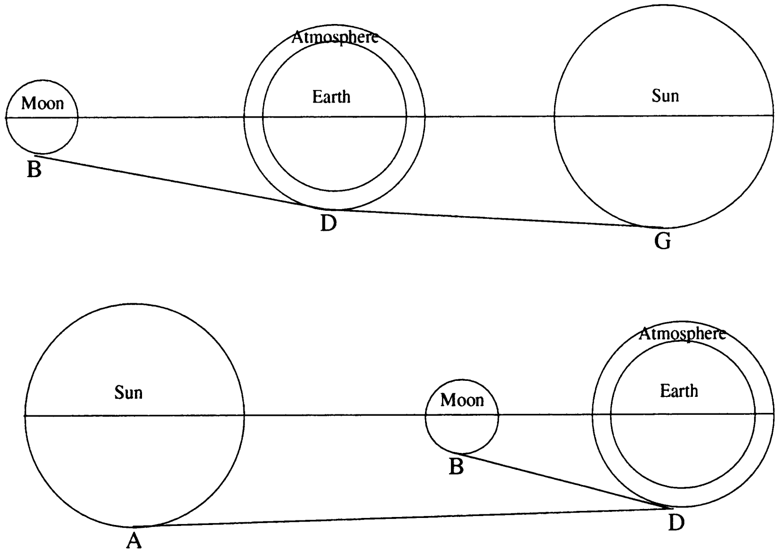


FIGURE 60

[8] The shadow of the

الأرض وجد مخروطيا، بأن القمر كلما كان أبعد عن[1] الأرض، فمكثه في الخسوف أقل من التساوي في العرض، فالشمس أعظم من الأرض، وهي من القمر.

[٩] وقيل إذا كانت الشمس في الأوج، فرأس المخروط[2] يصل إلى فلك الزهرة، وأن [أ ٥٠ظ] كان في الحضيض لا.

[١٠] وإذا توهم على المخروط دائرة موازية لقاعدته تسمى دائرة الظل، مركزها على منطقة البروج وقطرها مثل قطر[3] صفحة القمر، وثلاثة أخماسه في كل بعد. [ب ٢٢٥ظ، ج ٤٦ظ، ف ٣٠١ظ، خ ٥١و] فإذا كان نصف قطر هذه يه[4] دقيقة، فنصف قطر تلك كد،[5] [أ ٥١و، هـ ٣٠ظ] وفضل هذا على ذلك ط، ومجموعهما لط. فعرض القمر إن ساواه أو كان أكثر منه، لا ينخسف، [ف ٣٠٢و] وإن كان أقل ينخسف.

[١١] فإن كان أكثر من كد، ينخسف أقل من النصف. وإن كان مثله فالنصف. وإن كان أقل وأكثر من ط، فأكثر من النصف. وإن كان ط فالكل، بلا مكث. وإن كان [خ ٥١ظ] أقل، فمعه.

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[1] عن: من [ج]

[2] المخروط: الكلمة، سقطت [ب]

[3] قطر: الكلمة، سقطت [أ، ب]

[4] يه: ٢ [ج]

[5] كد: الكلمة، غير واضحة [ب]

earth is found to be conical, since when the moon is farther away from the earth, the duration of its eclipse is less than (it would be) had the width (of the shadow) been equal. Thus, the sun is larger than the earth, and the latter (is larger) than the moon.

[9] Moreover, it is maintained that if the sun is at the apogee, then the tip of the cone reaches the orb of Venus. If, [f. 50v] it (i.e. the sun) is at the perigee, (the tip of the cone) will not (reach this orb).

[10] Consider a circle on the cone parallel to its base, which we call the shadow circle. Let its center fall on the cincture of the ecliptic, and let its diameter at every distance be equal to one and three fifth the diameter of the disc of the moon. Thus if the radius of the latter is 15 minutes, then the radius of the former is 24 (minutes), [f. 51r] and the difference between the two is 9, while their sum is 39. Now, if the latitude of the moon is either equal to or greater than this (sum), then it will not be eclipsed, whereas it will be eclipsed if it is less than that.

[11] If it (i.e. the latitude of the moon) is greater than 24, then less than half (the moon) will be eclipsed. If (the latitude is) equal (to 24), then half (the moon will be). If it is less (than 24) and more than 9, then more than half. If it were 9, then all (the moon will be eclipsed), without duration (of totality). And if less (than 9), then (all the moon will be eclipsed), and (the totality) will have a duration.

[١٢] [ج ٤٧و] ونصف السدس يسمى إصبعا، فالمطلقة [ب ٢٢٦و] من القطر، والمعدلة من الجرم.

[١٣] وإذا حال القمر بيننا وبين الشمس يقع الكسوف. وهو قد يقع في موضع دون موضع آخر، لاختلاف المنظر. بخلاف الخسوف، إذ لا اعتبار به فيه.

[١٤] فأن كان العرض المرئي، أي المعدل باختلاف المنظر في العرض، وقت الاجتماع المرئي، وهو المعدل به في الطول، أكثر من نصف قطريهما أو مساويا، لاينكسف، وإن كان أقل ينكسف .

[١٥] وقطرها[١] وجد من لا دقيقة إلى لد، وقطره من كط إلى لو. فأن كان أكثر من نصف قطر القمر ينكسف أقل من النصف. /وإن كان مثله، فالنصف.[٢] وإن كان أقل لكن أكثر من دقيقتين ونصف، فالأكثر. وإن لم يكن أكثر من ذلك، فأن كان جرمه أعظم [ف ٣٠٢ظ] من جرمها، والعرض مساو للفضل أو أقل،[٣] فالكل، [أ ٥١ظ] وإلا فالأكثر. وإن عدم العرض ينكسف الكل بلا مكث، أو معه، أو تبقى حلقة النور.

[١٦] [ب ٢٢٦ظ، ج ٤٧ظ، خ ٥٢و، هـ ٣١و] وحد الخسوف أن

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[١] قطرها: قطره [ج]

[٢] /وإن...فالنصف: العبارة، سقطت [ج]

[٣] للفضل أو أقل: العبارة، غير واضحة [أ]

[12] One half of a sixth [i.e. 1/12] is called a digit (*iṣba'*). If (used in a) general (manner), then (it refers) to the diameter, whereas, when qualified, (it refers) to the celestial body.

[13] If the moon falls between us and the sun, then a solar eclipse occurs. Because of parallax, it (i.e. the solar eclipse) could occur in certain locations and not in others. This is opposite to the lunar eclipse in which there is no regard for (parallax).

[14] Now, at the time of the apparent conjunction, which is adjusted in longitude due to it (i.e. parallax), if the apparent latitude, that is the one which is (also) adjusted in latitude due to parallax, is either greater than or equal to (the sum of) their radii (i.e. the sun and the moon), then it (i.e. the sun will not be eclipsed, while if (the latitude) is less, then (the sun) will be eclipsed.

[15] Its (i.e. the sun's apparent) diameter is found to be between 31 and 34 minutes, whereas (that of the moon) is between 29 and 36 (minutes). Thus if (the apparent latitude of the moon) is greater than the radius of the moon, then less than half the sun will be eclipsed. If (the apparent latitude) is equal (to the radius of the moon), then half (the sun will be eclipsed). If (the latitude) is less (than the radius), but more than two and a half minutes, then most (of the sun will be eclipsed). If (the latitude) is not more than (two and a half minutes), and if the (apparent) size (of the moon) is greater (than that of the sun), while the latitude is either equal to, or less than the difference (between the two radii), then all of (the sun will be eclipsed). [f. 51v] Otherwise, (if in the last case the apparent size of the moon is less than that of the sun, then) most (of the sun will be eclipsed). (Finally), if there is no latitude, then the whole of the sun will be eclipsed, with or without duration, or a ring of light will be left.

[16] The lunar eclipse limit is

يكون البعد بين الشمس وإحدى العقدتين، وقت الاستقبال، يب[1] درجة.

[١٧] [ف ٣٠٣و] وحد الكسوف أن تكون الشمس بعد الرأس، أو قبل الذنب، ببعد يح درجة. وعلى العكس، ببعد سبع. لأن اختلاف المنظر يقرب القمر من الشمس ثمة، ويبعده هنا. [أ ٥٢و، ج ٤٨و، خ ٥٢ظ]

[١٨] فيمكن خسوفان بينهما خمس أشهر. يكون الأول بعد إحدى العقدتين، والثاني قبل الأخرى. كما كانت الشمس في أواخر[2] الجدي، والرأس في د[3] درجة منه، ووقع خسوف. فأذا قطعت الشمس خمسة بروج، والرأس ثماني درجات على خلاف التوالي، بقي البعد بينها وبين الذنب يب درجة، فيكون الخسوف. وكذا الكسوفان.

[١٩] [ب ٢٢٧و، ف ٣٠٣ظ] لكن لا يكون شيء منهما تاما. ولا يمكن خسوفان بينهما سبعة أشهر: فإن الأقرب أن يكون الأول قبل إحدى العقدتين. والشمس تفرض بطيئة تقطع ره درجة، والرأس يا درجة، إلى خلاف التوالي. فالشمس تخرج عن حد الخسوف. [أ ٥٢ظ، خ ٥٣و]

[٢٠] ويمكن الكسوفان في سبعة أشهر، إن كان الأول قبل الذنب والآخر بعد[4] الرأس.

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[1] يب: ب [ف]

[2] أواخر: آخر [أ، ب، ج]، وصححت للمعنى

[3] د: ك [ب]

[4] بعد: قبل [أ، ب، ج]، وصححت للمعنى، وقد وردت بهذا الشكل في الطوسي [تذكرة، ٥٨و]

a distance between the sun and one of the two nodes, at the time of opposition, of 12 degrees.

[17] The solar eclipse limit is either when the sun is past the head, or before the tail, at a distance of 12 degrees (from either), or (when the sun is) on the opposite sides (of the nodes), at a distance of seven degrees (from either one). (This is so) because the parallax brings the moon closer to the sun in the former (case), and (further) separates them in the latter (case).

[18] [f. 52r] It is thus possible to have two (successive) lunar eclipses which are (only) five months apart. The first (occurs) after one of the two nodes, while the other would (occurs) before the next one. (Consider, for example,) the case when a lunar eclipse takes place, while the sun is (around) the end of Capricorn, and the head (ascending node) is at four degrees (Capricorn). If next the sun moved through five zodiacal signs, and the head (moved) eight degrees in the direction opposite to the sequence of the signs, then the resulting distance between it (i.e. the sun) and the tail (descending node) will be 12 degrees. A (second) lunar eclipse could thus occur. The same (applies) for two solar eclipses.

[19] Neither of the above (solar eclipses) would, however, be total. (Moreover), it is not possible to have two (successive) lunar eclipses which are seven months apart: (consider) the closest (possibility) when the first (lunar eclipse) occurs before one of the nodes. Let the sun travel slowly through 200;5 degrees, and the head through 11 degrees in the direction opposite to the sequence of the signs. The sun will then move outside the lunar eclipse limit.

[20] [f. 52v] It is possible to have two (successive) solar eclipses which are seven months apart, but only if the first occurs before the tail, and the second after the head.

[٢١] [هـ ٣١ظ] والخسوف والكسوف [ج ٤٨ظ] في شهر. لا الخسوفان فيه، ولا الكسوفان، إلا في بقعتين مختلفتي جهة العرض.[١]

[٢٢] [ب ٢٢٧ظ، خ ٥٣ظ، ف ٣٠٤و] واعلم أن ابتداء الإظلام والانجلاء في الخسوف من جانب المشرق، وفي الكسوف من المغرب، لأنهما بحركة القمر.

[١] العرض: للعرض [ب]

[21] (Furthermore), it is possible to have both a lunar and a solar eclipse in one month. Neither two lunar, nor two solar eclipses, (however), can occur in the same month, except (if two solar eclipses occur) in two locations, such that the directions of their latitudes are opposite.

[22] Note that the beginnings of immersion and of clearance in a lunar eclipse are from the east side (of the moon), whereas in a solar eclipse they are from the west side (of the sun), because they (i.e. the immersion and clearance) result from the movement of the moon.

[١] [أ ٥٣و] فصل: في الظهور والاختفاء.

[٢] العلويات، إذا خرجت عن[١] الاحتراق، صارت مشرقة. ثم يتقدم طلوعها شيئا فشيئا، إلى أن تطلع، عند المقابلة، وقت الغروب، فترى في جميع الليل. ثم يقع في النهار، و يتقدم شيئا فشيئا، فترى في بعض الليل، إلى أن تصير مغربة. ثم تختفي.

[٣] والسفليان إذا خرجا عن الاحتراق مستقيمين، سبقا الشمس، مغربين. /فيظهران، بعد غروب الشمس، [ج ٤٩و] في المغرب. ثم رجعا، فاحترقا. ثم ظهرا مشرقين.[٢]

[٤] والزهرة، في الإقليم الرابع، إذا احترقت في الحوت، راجعة، لا تخفى بكرة وعشيا. لأنها في حضيض التدوير، فيعظم جرمها. وأيضا ميل حضيض تدويرها يبتدي [ف ٣٠٤ظ] من حضيض الحامل، وهو القوس، إلى أن يبلغ غايته عند إحدى[٣] العقدتين في الحوت، فيعدم الميل الأول، لكن ميل حضيضها في الغاية الشمالية؛ فيطلع قبل درجتها ويغرب بعدها.

[٥] [خ ٥٤و، هـ ٣٢و] وإن احترقت في السنبلة، مستقيمة، تخفى ستة عشر يوما. لأنها في الذروة، فيصغر[٤] جرمها.

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[١] عن: من [أ، ج]

[٢] /فيظهران...مشرقين: العبارة، شرح [ج]

[٣] إحدى: اجتماع [أ، ج]

[٤] فيصغر: فيصير [ب]

[1] [f. 53r] Chapter (12): On Visibility and Invisibility.

[2] If the superior planets move out of the glare (of the sun), they (rise) from the east. Their rising then advances gradually, until they reach opposition (to the sun), whereupon they will rise at sunset, and are seen throughout the night. Their (rising) will then take place during the day, and advances gradually, (during which time) they (i.e. the planets) are seen during part of the night, until they rise in the west. They then become invisible.

[3] If the two inferior planets, during their direct motion, move out of the glare (of the sun), then they will move ahead of the sun, and they will rise in the west. They thus appear in the west after sunset. Next, they retrograde, and they move into the glare (of the sun). (Finally), they appear from the east.

[4] (Now, for an observer) in the fourth climate, if Venus retrogrades into the glare (of the sun) in Pisces, then it neither becomes invisible in the morning nor in the evening. (This is so) because it is at the epicyclic perigee, where its (apparent) size increases. Moreover, the inclination of its epicyclic perigee begins at the deferent's perigee, which is (in) Sagittarius, and it reaches its maximum at one of the two nodes in Pisces, where the first inclination vanishes. (At this point), however, the inclination of its epicyclic perigee will attain its maximum northerly value; it thus rises before (the point which has) its (i.e. Venus's latitude) degrees, and sets after it.

[5] If, (however, Venus) moves into the glare in Virgo, during its direct motion, then it becomes invisible for sixteen days. (This is so) because it is at the epicyclic apogee, where its (apparent) size is smaller.

[٦] وفي التحفة علل أيضا بطول مغارب الحوت وقصر مغارب السنبلة، فأن الحوت قصير المطالع، طويل المغارب، والسنبلة بالعكس. وفيه نظر، لأن طول مغارب[١] الحوت يعارضه قصر مطالعه، وقصر مغارب السنبلة يعارضه طول مطالعها. [أ ٥٣ظ، ب ٢٢٨و]

[٧] وفيها، أنها في الاستقامة بطيئة التباعد عن الشمس لكونه بالخاصة فقط. بخلاف التباعد في الرجوع، فأنه بالمركز والخاصة. وفيه نظر، لأن وسطها مثل وسط الشمس، فلا يبعد عنها إلا بقدر الخاصة، رجوعا واستقامة. لكن هنا[٢] شئ آخر، وهو أن الخاصة، وهي في حضيض التدوير، ترى أكثر منها وهي في الذروة.

[٨] وعطارد لا يرى عشيا حوالي رأس الميزان، لقلة مغاربه،[٣] ولا في حدود أوجه، لأن القطر المسائي [ج ٤٩ظ، ف ٣٠٥و] في غاية البعد الجنوبي. فيغرب قبل درجته. ولا غدوة حوالي رأس الحمل، لقلة[٤] مطالعه، ولا في حدود مقابل أوجه، لأن القطر الصباحي في غاية البعد الجنوبي. والله أعلم.[٥]

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[١] مغارب: مطالع، ثم شطبت وكتب تحتها مغارب [ب]

[٢] هنا: ههنا [ج]

[٣] مغاربه: مقارنه [ج]

[٤] لقلة: بقلة [ب]

[٥] والله أعلم: العبارة، سقطت [أ، ج]

[6] In the *Tuḥfa*, (the above phenomena) was also attributed to the length of the rising time of Pisces, and the shortness of the setting time of Virgo, because Pisces has a long rising time and short setting time, and conversely for Virgo. This, however, is disputable, because the longness of the setting time of Pisces is countered by the shortness of its rising time, and the shortness of the setting time of Virgo is countered by the length of its rising time.

[7] [f. 53v] (It is) also (mentioned) in it (the *Tuḥfa*), that during direct motion (Venus) has slow elongation from the sun, since it is only due to anomalistic motion. (This is) in contrast to elongation during retrograde motion, which is due to both the (motion of the) center and the anomalistic motion. This (too), is disputable, because the mean position (of Venus) is similar to the mean position of the sun, which means that, during both retrograde and direct motions, (Venus) only elongates (from the sun) by a value which is equal to the anomalistic motion. (What is relevant) here, however, is something else, namely that, at epicyclic perigee, the anomaly appears to be larger than it does at epicyclic apogee.

[8] Mercury, (on the other hand), is not visible in the evening around the beginning of Libra, due to the smallness of its setting time, neither (is it visible) around its (deferent) apogee, because the evening diameter will then be at its farthest southerly distance. It thus sets before (the point which has) its (latitude) degree. (Moreover), it (i.e. Mercury) has no matutine (visibility) around the beginning of Aries, due to the shortness of its rising time, neither (is it visible) around the point which is diametrically opposite to its (deferent) apogee, because the morning diameter is at its farthest southerly distance. And God knows best.

[١] تعديل مباحث الأرض،[1] وما يتعلق بها.

[٢] [خ٥٤ظ] لما كانت الأرض كرية، في الوسط، كان الواقف عليها رجله إلى المركز، وهو التحت، ورأسه إلى المحيط، وهو الفوق، من جميع الجوانب.

[٣] والسائر على الأرض يصير سمت رأسه في كل وقت جزءاً آخر. فأن فرض ثلاثة أشخاص في موضع، فدار الأول على الأرض ذاهبا إلى المشرق، جانبا إلى المغرب، والثاني بالعكس، وأقام الثالث. فعدوا الأيام من يوم معين إلى يوم معين، كان[2] للواقف عدد، وللمشرقي ذلك مع واحد، وللمغربي ذلك إلا واحد. لأن اليوم بليلته للمشرقي ناقص بمقدار حركته، عنه للواقف.[3] /فالنقصانات إذا اجتمعت صارت دورا [ب ٢٢٨ظ] واحدا زائدا على عدد أيام الواقف.[4] [أ ٥٤و] وللمغربي زائد. [ف ٣٠٥ظ] فعدد أيامه ناقص عن عدد أيام الواقف بواحد.

[٤] وهذا مما يستغرب. فيسأل: أنه كيف يكون يوم واحد خميسا [هـ ٣٢ظ] لشخص، جمعة لآخر، سبتا لثالث!

[٥] ولما توهم المعدل قاطعا للأرض، حدثت دائرة عليها [ج ٥٠و] تسمى خط الاستواء. [خ ٥٥و] والعمارة وقعت في الربع الشمالي. وقد

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[1] الأرض: العروض [ب]

[2] كان: وكان [أ، ب]

[3] عنه للواقف: العبارة، في الهامش [ج]

[4] /فالنقصانات...الواقف: العبارة، شرح [ج]

[1] [Chapter 13] Adjustments (Regarding) Topics Related to the Earth and other (Matters).

[2] Since the earth is spherical and in the center, then the foot of a person standing on its surface (points) to the center, which is the invisible (part of the firmament), whereas his head (points) towards the circumference, which is the visible (part of the firmament). (This is true) from all directions (on the surface of the earth).

[3] The zenith of a (person) walking on the (surface of the) earth falls at different points at different times. Consider three people at one locality, and let the first walk around the earth towards the east, away from the west, while the second (walks in the) opposite (direction). Let the third stay (in the original locality). If then they count the days from one specific day to another specific day, then a certain number (would correspond) to the one who does not move, while that (same number) plus one (would correspond) to the one (heading) east, and that (number) less one (would correspond) to the one (heading) west. (This is so) because one nychthemeron for the person (heading) east is smaller than the corresponding (nychthemeron) for the one who is not moving, by a value which is equivalent to the motion of the former. Now, if the diminutions are added, then they amount to one whole revolution above the number of days for the one who does not move. [f. 54r] (The nychthemeron) for the person heading west is greater (than for the one who does not move). The number of his days is thus one (day) less than the number of days for the one who does not move.

[4] This is difficult to understand. People thus wonder: how could the same day be a Thursday for one person, a Friday for another, and a Saturday for yet a third.

[5] Now if we imagine that the (celestial) equator intersects the earth, then a circle called the (terrestrial) equator will be formed on it. The inhabited (portion of the earth) falls in the northerly quarter (of the globe).

تحير أهل هذا الفن في سببه. وقد مر في أول الكتاب أن موضع البحر لابد أن يكون أقرب إلى مركز العالم، ليستقر[١] فيه الماء، ولا يسيل إلى الجوانب الأخر من الأرض. فصار السبب ارتفاع المواضع المنكشفة وانخفاض موضع الماء. خلقه بحكمة خالق[٢] الحيوانات في المواضع المرتفعة. فنعم ما قال صاحب التذكرة: إن[٣] السبب ليس إلا العناية الإلهية.

[٦] ثم المعمورة قسمت[٤] على سبعة أقاليم بخطوط موازية. ولنضع النهار الأطول، وعروض الأقاليم في هذا الجدول:

[١] ليستقر: استقر [أ، ب]

[٢] خالق: خلق [أ، ب، ج]، وهي كتابة قرآنية

[٣] إن: الكلمة، في الهامش [ج]

[٤] قسمت: قسم [أ، ب]

The practitioners of this art wonder about the cause (of the above phenomenon). It is mentioned in the beginning of this book, however, that the location of the sea must be closer to the center of the world, so that water settles in it, and not flow in the other directions of the earth. The reason is thus the elevation of raised localities, and the depression of the location of water. Indeed, (everything) is created for a reason by the One Who created all animals in elevated localities. The author of the *Tadhkira* expressed it eloquently when he said: the reason is nothing but the Divine Providence.

[6] Next, the inhabited (portion of the earth) is divided by parallel lines into seven climates. So let us list the (hours of the) longest days, and the latitudes of the climates, in the following table:

الإقليم[1]	ساعات النهار الأطول في المبدأ	عرض المبدأ	ساعات النهار الأطول في الوسط	عرض الوسط
١	عند البعض يب ة وعند البعض يب مه	عند البعض ه يه وعند البعض يب مه	يجـ ة	يو لز
٢	يجـ	ك كز	يجـ ل	كد م
٣	يجـ	كز ل	يد ة	ل م
٤	يد يه	لجـ لز	يد ل	لو كب
٥	[يد مه]	لح	يه ة	ما يه
٦	يه يه	مجـ كجـ	يه ل	مه كا
٧	يه مه	مز يب	يه ة	مح

[1] الاقليم ١: الاقليم الأول؛ ٢: الاقليم الثاني، إلخ...[أ]؛ الجداول فارغة في [ج]

	Hours of the longest day at beginning	Latitude of the beginning	Hours of the longest day at the middle	Latitude of the middle
First Climate	According to some 12;0 According to others 12;45	According to some 0;0 According to others 12;40	13;0	16;37
Second	13;15	20;27	13;30	24;40
Third	13;45	27;30	14;0	30;40
Fourth	14;15	33;37	14;30	36;22
Fifth	14;45	38;54	15;0	41;15
Sixth	15;15	43;23	15;30	45;21
Seventh	15;45	47;12	16;0	48;52

[٧] وبعد الأقاليم السبعة يكون النهار الأطول والعرض هكذا: [١]

العرض	ساعات النهار الأطول في كل عرض	العرض	ساعات النهار الأطول في كل عرض
ند	يز ساعة	تمام الميل	كد
نح	يح	سز يه	شهر
سا	يط	سط مه	شهران
سجـ	ك	عجـ ل	ثلاث أشهر
سد ل	كا	عح ل	أربعة
سه	كب	[عد ل]	خمسة
سو	كجـ	ربع الدور	ستة أشهر

[١] الجداول فارغة في [ج]

[7] Beyond the seven climates the longest day and (its corresponding) latitude is as follows:

Latitude	Hours of the longest day in every latitude	Latitude	Hours of the longest day in every latitude
54	17	Complement of the maximum inclination	24
58	18	67;15	One month
61	19	69;45	Two months
63	20	73;30	Three months
64;30	21	78;30	Four
65	22	84	Five
66	23	Quadrature	Six months

[١] [ف ٣٠٦و] فصل [ب ٢٢٩و] في خواص[١] الربع الشمالي:

[٢] طوله نصف الدور. ومبدأه ساحل بحر[٢] المغرب، وعند البعض [أ ٥٤ظ] جزائر الخالدات، وهي في غربي الساحل تبعد عشر درجات. ووسطه على خط الاستواء /قبة الأرض.

[٣] ومبدأ العرض خط الاستواء،[٣] والدور فيه دولابي. ودائرة أفقه تنصف جميع المدارات اليومية، لكونها مارة على قطبي المعدل. / فيتساوى الليل والنهار دائما.[٤] [خ ٥٥ظ] /ولكل نقطة طلوع وغروب، [ج ٥٠ظ] وزمان ظهورها كزمان خفائها. قال في التذكرة: فإن كان فيه تفاوت، كان بسبب اختلاف الحركة[٥] الثانية في النصفين، وهو غير محسوس. أقول: الحركة[٦] الثانية غير مختلفة، لكن مطالع قوس[٧] الحركة مختلفة، فيختلف زمان الظهور والخفاء.

[٤] ثم لاختلاف الليل والنهار سبب[٨] آخر، وهو أن تقويم الشمس

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[١] خواص: حقائق [هـ]

[٢] بحر: البحر، ثم شطبت أل التعريف [ج]

[٣] /قبة...الاستواء: العبارة، سقطت [هـ]

[٤] /فيتساوى...دائما: العبارة، شرح [أ]

[٥] الحركة: الحركات [هـ، خ]

[٦] الحركة: الحركات [ب]

[٧] قوس: القوس، ثم شطبت أل التعريف [أ]

[٨] سبب: سند [خ]

[1] Chapter [14]: On the Characteristics of the Northern Quarter (of the Earth).

[2] Its longitude is half a revolution. It (i.e. the northern quarter of the earth) starts at the coast of the Western Sea. According to some (it starts) [f. 54v] at the Fortunate (*Khalidāt*) Isles, which are west of the coast by a (longitudinal) distance of ten degrees. Its (the quarter's) middle on the terrestrial equator is the dome of the earth (*Qubbat al-Arḍ*).

[3] The beginning of latitude is the equator, where the (daily) rotation (of the sun) is wheel-like (i.e. *sphaera recta*). The horizon circle (for a locality on the equator) bisects all the day circles, because it passes through the two poles of the equator. Therefore, the day and the night will always be equal. Moreover, every point (on the celestial sphere) has a rising and a setting, and the duration of its visibility equals to the duration of its invisibility. Now, according to the *Tadhkira*, if there is a discrepancy between the two (above durations), then this is a result of the variation in the second motion in (either one of) the two hemispheres, and this (variation) is not detectable. I say, (however), that the second motion does not vary, rather what varies is the ascensions of the arc of motion, and the durations of both visibility and invisibility differs (accordingly).

[4] Furthermore, there is another cause for the variation of (the durations of) the night and the day, namely that the true position of the sun

مختلف دائما. فمطالع قسي الحركة التقويمية[١] مختلفة باختلافين: اختلاف[٢] تلك القسي، ثم اختلاف المطالع.

[٥] ثم الشمس تمر[٣] على سمت الرأس مرتين،[٤] في نقطتي الاعتدالين،[٥] وقطبا[٦] البروج حينئذ على الأفق.[٧] فتقطع المنطقة الأفق على زوايا قائمة. [هـ ٣٣ظ] وتبعد في الانقلابين بقدر الميل الكلي. فيكون ثمة ثمانية [ف ٣٠٦ظ] فصول. ولكون[٨] دائرة الأفق من دوائر الميل،[٩] كان [أ ٥٥و] سعة مشرق[١٠] نقطة من منطقة البروج [ب ٢٢٩ظ] بقدر ميلها، وكذا سعة مغربها.

[٦] [خ ٥٦و، هـ ٣٤و] وقيل[١١] بقاعه أعدل البقاع، لأن الشمس تزول عن سمت الرأس سريعا، لأن حركة الميل في نقطتي الاعتدالين

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[١] التقويمية: التقويمة [هـ]

[٢] باختلافين: إختلاف: به باختلاف [هـ]

[٣] تمر: ثم [هـ]

[٤] مرتين: الكلمة، غير واضحة، وأثبتت في الهامش [ب]

[٥] الاعتدالين: الاعتلالين [ج]

[٦] قطبا: قطب [ج]

[٧] /ولكل...الأفق: العبارة، شرح [ب، هـ، خ]

[٨] لكون: يكون [هـ]

[٩] الميل: المثل [هـ]

[١٠] مشرق: الكلمة، تحت السطر [ب]

[١١] وقيل: قيل [ج]

always varies. Therefore, the ascensions of the arcs of true motion vary due to two changes: the variation of these arcs, and then the variation in the ascensions.

[5] Next, the sun passes through the zenith (when the zenith is in turn) at the two equinoctial points twice, and the poles of the ecliptic then fall on the horizon. The cincture (of the ecliptic) thus intersects the horizon at right angles. (Moreover), at the two solstices, it (the sun) moves away (from the zenith) by an amount equal to the obliquity of the ecliptic. Thus, at these (positions), eight seasons are obtained. (Furthermore), since the horizon circle is one of the declination circles, therefore, [f. 55r] the rising amplitude of a point on the cincture of the ecliptic equals its declination, and the same for its setting amplitude.

[6] It is maintained that its regions (i.e. those of the equator) are the most moderate, because the sun moves quickly away from the zenith, since the variation in the declination is most rapid at the two equinoctial points,

أسرع ما تكون، بخلاف المنقلب، إذا كان على سمت الرأس. [ج ٥١و] والمسامتة، وإن كانت مسخنة، فدوامها أبلغ فيه.

[٧] ورد بأن البقاع التي ارتفاع الشمس في صيفها كارتفاعها في شتاء خط الاستواء، حر صيفها شديد. فكذا شتاء خط الاستواء. فانظروا إلى حال صيفه!

[٨] ومنع، بأن حر صيف تلك البقاع يمكن أن يكون لطول النهار. وهذا ليس بقوي، [ف ٣٠٧و] إذ طول النهار يظهر في آخره، لكن الحر قبله.

[٩] فصاحب التذكرة قال: إن عني بالاعتدال[١] تشابه الأحوال، فخط الاستواء أعدل. وإن عني تكافؤ الكيفيتين فلا.

[١٠] /وأما ما ليس على خط الاستواء، ولم يكن عرضه ربع الدور، فالدور فيه حمائلي. وكل[٢] كوكب على معدل النهار، فزمان ظهوره كزمان خفائه. وما بعد عنه، فأن كان في جانب القطب الظاهر، وارتفاعه كارتفاعه أو أقل، لا يغيب أبدا. وإن كان أكثر، يغيب. ويكون قوس نهاره أعظم [أ ٥٥ظ] من قوس ليله بقدر ضعفي تعديل النهار. وفي جهة القطب الخفي على العكس.[٣]

[١١] [ب ٢٣٠و، خ ٥٦ظ] والنقطتان المتساويتا البعد عن المعدل،

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[١] بالاعتدال: فالاعتدال [ب]

[٢] وكل: فكل [ب]

[٣] /وأما...العكس: العبارة، شرح [أ]

in contrast to (the case) when the zenith is at the solstice. (It is also maintained that) although the passage (of the sun) through the zenith (of the locality) is a cause of heating, its duration (in this position) is more effective (in this heating).

[7] (The above argument) is, (however), rejected, because if we consider a region in which the altitude of the sun in the summer is equal to its altitude during a winter at the equator, then the heat of the summer (of this region) is extreme. The winter of the equator would thus be equally (hot). So imagine what its summer would be!

[8] (One may respond to this latter argument) by denying that (the summer of those regions is similar to the winter of the equator), since the heat of those regions could result from the length of the day. This, however, is not a strong (argument), since the length of the day affects its end, whereas the heat appears earlier (during the day).

[9] The author of the *Tadhkira* thus says: if what is meant by temperate (climate, *i'tidāl*) is the similarity of conditions, then the equator is more temperate. If, however, the equivalence of the qualities is meant, then (the equator) is not (the most temperate part of the earth).

[10] In the case of (localities) which do not fall on the (terrestrial) equator, and whose latitudes are not a (full) quadrant, the rotation (of the ecliptic) is wobbly (*ḥamā'ilī*). If then a star is situated on the equator, the time of its visibility will be equal to the time of its invisibility. Now, (consider a star) which is located away from it (the equator): if it (the star) is on the side of the visible pole, such that its altitude is equal to or less than the altitude (of the pole of the equator), then (the star) never sets. If, however, (the distance between the pole of the equator and the star) is more (than the altitude of the pole), then (the star) will set. Its day arc will then be greater [f. 55v] than its night arc by double the value of the equation of daylight. If (the star falls) on the side of the invisible pole, then the opposite (holds).

[11] The two points which are equidistant from the equator,

في جانبيه،[١] زمان ظهور إحديهما كزمان خفاء الأخرى.

[١٢] /وتعديل النهار هو نصف الفصل بين نهار البلد ونهار الاستواء. وهو في أجزاء البروج الفصل بين مطالعها بالبلد وخط الاستواء. ويوجد بطريقتين: (١)[٢] أن تمر دائرة ميل على مركز الكوكب، وهو على أفق المشرق، في جزء من البروج الشمالية.[٣] [ج ٥١ظ] فحدث مثلث تحت الأرض، أحد أضلاعه سعة المشرق، [ف ٣٠٧ظ] والثاني قوس من دائرة الميل بين رأس السرطان والمعدل. والثالث تعديل النهار. فإذابلغ ذلك الجزء الأفق الغربي[٤] تمر دائرة ميل أخرى عليه، فحدث مثلث تحت الأرض، أحد أضلاعه سعة المغرب، والآخران[٥] كما مر. فالقوس من المعدل تعديل النهار، فنهار[٦] البلد يفضل على نهار الاستواء بهما. [هـ ٣٤ظ] لأن ذلك الجزء يطلع ويغيب، في خط الاستواء، مع نقطة تقاطع دائرة الميل والمعدل. فأحداهما[٧] نصف الفضل.

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[١] جانبيه: جانبه [أ]

[٢] (١): الأول [ب، ف]

[٣] /وتعديل...الشمالية: العبارة، سقطت، وأضيفت في الهامش [ب]

[٤] الغربي: الكلمة، سقطت [أ، ب]

[٥] الآخران: الآخر [ب]

[٦] فنهار: فيها و [ج]؛ بهما [ب]

[٧] فأحداهما: فأحديهما [أ، ب، ج]

from either side, are such that the time of visibility of one of them is equal to the time of invisibility of the other.

[12] The equation of daylight is one half the difference between (the lengths of) the day of a locality and the day at the equator. For points on the ecliptic orb, it is the difference between the oblique ascensions (of those points) and the equator. (This equation) can be determined in two ways: (1) let a declination circle pass through the center of the planet when it falls on the eastern horizon, at some point in the northern zodiacal signs. A (spherical) triangle is thus obtained below (the horizon of) the earth, such that one of its sides is the rising amplitude. The second (side) is an arc of the declination circle (marked) between the beginning of Cancer--(assuming that it is the ascending point on the horizon)--and the equator. The third (side) is the equation of daylight. Now if the above point reaches the western horizon, then another declination circle will pass through it. A (second) triangle is then obtained below the (horizon of the) earth, such that one of its sides is the setting amplitude , and the two other (sides) are as mentioned above. The arc on the equator is therefore the equation of daylight, and the day of the locality exceeds the day of the equator by the value of both (eastern and western equations). (The above is true) because, (for a locality) on the equator, the above point (the sun) rises and sets together with the point of intersection of the declination circle and the equator. Each one of the two (equations of daylight) is therefore half the difference (between the day at the locality and the day at the equator).

[١٣] (٢)[1] أن نكتفي بدائرة ميل واحدة، تمر على مطلع الاعتدال ومغيبه، عند كون الكوكب على أفق المشرق. فقطعت /مدار الكوكب، وهو[2] دائرة موازية للمعدل، على نقطتين فوق الأفق، شرقا وغربا. فحصل قوسان من المدار، بين نقطتي التقاطع وبين الأفق، شرقية وغربية. كل منهما تعديل النهار. ففي خط [خ ٥٧و] الاستواء [أ ٥٦و] يطلع ويغيب مع نقطتي التقاطع. فالقوسان فضل نهار البلد على نهار الاستواء، فأحدهما[3] نصفه.

[١٤] وهذه القوس من المدار شبيهة القوس من المعدل في الطريق الأول، لأنه إذا مرت دائرة ميل بالطريق الأول، والأخرى بالطريق الثاني، فالقوسان واقعتان بينهما. وهما متوازيتان فكانتا شبيهتين.

[١٥] [ب ٢٣٠ظ، ج ٥٢و، ف ٣٠٨و] وإذا كان الكوكب في البروج الجنوبية، ففي الطريق الأول المثلثان فوق الأرض، وفي الثاني تحتها. فقوس نهار الاستواء يفضل على قوس نهار البلد بالقوسين المذكورين. فأحداهما[4] نصف الفضل. [أ ٥٦ظ، ب ٢٣١و، ج ٥٢ظ، ف ٣٠٨ظ، هـ ٣٥و، خ ٥٧ظ]

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[1] (٢): الثاني [ف]

[2] /مدار...وهو: العبارة، سقطت، وأضيفت في الهامش [أ]

[3] فأحدهما: فأحديهما [ج]

[4] فأحداهما: فأحديهما [أ، ب، ج]

[13] Let us draw only one declination circle that passes through the vernal and autumnal equinoxes, when the star is at the eastern horizon. (The declination circle) intersects the day circle of the planet, which is a circle parallel to the equator, at two eastern and western points above the horizon. Two arcs are thus marked on the day circle, such that they fall between the two points of intersection and the east and west (points) of the horizon. Each of these (two arcs) is an equation of day light. (The above is true) because, (for a locality) on the equator, [f. 56r] (the star) rises and sets together with the two points of intersection. The two arcs are thus equal to the value of the day of the locality, less the day of the equator, and each one of them will be half that (value).

[14] The latter arc is equal to the arc of the equator (obtained) by the first method, because if a declination circle is issued according to the first method, and the second one is issued according to the second method, then the above arcs will fall between them. But the two (arcs) are parallel, therefore, they are equal.

[15] If, (on the other hand), the star is in the southern zodiacal signs, then by the first method, the two triangles will be above the (horizon of) the earth, whereas by the second (method) they will be below it. The day arc of the equator thus exceeds the day arc of the locality by (the value) of the two arcs mentioned. Either one of them will therefore be one half of the difference.

[١٦] وكل مدار، بعده عن المعدل[١] في جانب القطب الظاهر إن ساوى عرض البلد، يماس[٢] دائرة أول السموت على سمت الرأس. وإن[٣] كان أكثر، لا يماسها، ولا يصل إلى سمت الرأس. وإن كان أقل، يقطعها على نقطتين: شرقية وغربية.

[١٧] ثم البقاع التي لها عرض أقسام: (١) ما يكون عرضه أقل من الميل الكلي. فالشمس تمر على سمت الرأس مرتين في نقطتين ميلهما [ف ٣٠٩و] مثل عرض البلد. [خ ٥٨و] فيقع ظل[٤] نصف النهار في جهتين، ولا تكون فصول السنة متساوية.

[١٨] (٢)[٥] ما يكون مثله. فالشمس تمر [أ ٥٧و] بسمت الرأس مرة، فأحد قطبي البروج أبدي الظهور، والآخر أبدي الخفاء. ويكونان على الأفق، عند كون نقطة الانقلاب على سمت الرأس. ويكون الإظلال في جهة واحدة.

[١٩] وفي هذين العرضين، كل ما هو أبدي الظهور وأبدي الخفاء يحدث له بالحركة الثانية طلوع وغروب. وبعض ماله طلوع وغروب يصير بها أبدي الظهور، أو أبدي الخفاء.

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[١] المعدل: الكلمة، مقابلها في الهامش «ثلاثين» [ج]؛ +«ثلاثين ويكون» [ب]

[٢] يماس: مماس [ب]

[٣] وإن: فأن [ج]

[٤] ظل: الكلمة، سقطت، وأضيفت في الهامش [ج]

[٥] (٢): الثاني [ف]

[16] If a day circle falls on the side of the visible pole, such that its distance from the equator is equal to the latitude of the locality, then it will be tangent to the prime vertical at the zenith. If (the distance) is greater (than the latitude), then (the day circle) will not be tangent (to the prime vertical), and it will not reach the zenith. If smaller, then (the day circle) will intersect (the prime vertical) at two points: one easterly, and the other westerly.

[17] Next, the localities which have latitudes fall in (different) categories: (1) Those whose latitudes are less than the obliquity of the ecliptic. (There) the sun passes through the zenith at two points (along the ecliptic) whose declination is equal to the latitude of the locality. The midday shadow will then fall on two (different) sides, and the seasons of the year will not be equal.

[18] (2) (The second category of localities comprises) those whose (latitudes) are equal (to the obliquity of the ecliptic). (At those localities) the sun passes [f. 57r] through the zenith once, and one of the two poles of the ecliptic will be permanently visible, with the other permanently invisible. (Furthermore, these two poles will fall) on the horizon when the solsticial point crosses the zenith. (Moreover, meridian) shadows will always be cast towards one direction.

[19] In the above two latitudes, every (star) which is either permanently visible or permanently invisible will rise and set due to the second motion. (Moreover), some (of the stars) which have a rising and a setting become permanently visible or permanently invisible as a result (of this second motion).

[٢٠] [ج ٥٣و] أما في غير هذين العرضين، لا يلزم ما ذكر كليا. فأن أبدي الظهور، إن كان تمام عرضه مساويا لفضل[١] عرض البلد على الميل الكلي أو أقل، أي[٢] كان بعده عن قطب البروج الظاهر مساويا لارتفاعه الأسفل أو أقل، لا يحدث له طلوع [ب ٢٣١ظ] وغروب. وإن كان أكثر[٣] يحدث. [أ ٥٧ظ، خ ٥٨ظ، ف ٣٠٩ظ، هـ ٣٥ظ]

[٢١] (٣)[٤] ما يكون زائدا عليه، ناقصا من تمامه. /فالارتفاع الأعلى للشمس مثل الميل الكلي مع تمام عرض البلد. والارتفاع الأدنى[٥] مثل فضل تمام عرض البلد على الميل الكلي.[٦] [ج ٥٣ظ]

[٢٢] ثم فضل عرض البلد على الميل الكلي إن كان زائدا[٧] على عروض السيارات، لا يمر شئ منها بسمت الرأس. [ب ٢٣٢و، خ ٥٩و، ف ٣١٠و] قال بعض الأحكاميين لا يخرج في ذلك البلد نبي. وإن ساوى عرض سيارة فهي تمر مرة. وإن كان أقل فمرتين.

[٢٣] ويزداد تعديل النهار وسعة المشرق بازدياد العرض.

[٢٤] [أ ٥٨و، ب ٢٣٢ظ، ج ٥٤و، ف ٣١٠ظ، هـ ٣٦و، خ

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[١] لفضل: يفضل [ج]

[٢] أي: إن [ج]

[٣] أكثر: أقل [أ، ب، هـ]

[٤] (٣): الثالث [ف]

[٥] الأدنى: الأدنى، ثم صححت في الهامش إلى الأولى [ب]، الأولى [ج]

[٦] /فالارتفاع...الكلي: العبارة، شرح [ج]

[٧] زائدا: زائد [ج]

[20] The above will not at all be entailed at latitudes different from the above two. (Consider) a permanently visible (star): if the complement of its latitude is equal to, or less than the difference between the latitude of the locality and the obliquity of the ecliptic, that is if the distance (of the star) away from the visible pole of the ecliptic is equal to, or less than the latter's altitude, then (the star) neither rises nor sets. If (this distance is) more (than the latitude), then (the rising and setting of the star) will occur.

[21] [f. 57v] (3) (The third category of localities consists of) those whose (latitudes) are greater than (the obliquity of the ecliptic), and less than its complement. The highest altitude of the sun is equal to the sum of the obliquity of the ecliptic and the complement of the latitude of the locality. The lowest altitude then equals the difference between the complement of the latitude of the locality and the obliquity of the ecliptic.

[22] Next, if the difference between the latitude of the locality and the obliquity of the ecliptic is greater than the latitudes of the planets, then none of these would pass through the zenith. (Moreover), some astrologers maintain that no prophet would emerge in such localities. If, (on the other hand), the latitude of a planet is equal (to the obliquity of the ecliptic), then it (i.e. the planet) will pass once (through the zenith). If (the latitude is) less, then (the planet passes through the zenith) twice.

[23] Both the equation of daylight, and the rising amplitude increase when the latitude increases.

٥٩ظ] (٤)[1] ما يكون مساويا[2] لتمامه. فيكون مدار أحد المنقلبين أبدي الظهور. فيمر قطب البروج على سمت الرأس. فحينئذ تنطبق المنطقة على الأفق، ورأس السرطان /على نقطة الشمال، ورأس الحمل على نقطة المشرق. والآخران [أ ٥٨ظ] مقابلهما.[3] [خ ٦٠و، ف ٣١١و] /فمن رأس الجدي[4] إلي رأس السرطان طلع[5] في آن في النصف الشرقي من الأفق، وطلع من رأس السرطان إلى رأس الجدي مع كل دور المعدل.[6]

[٢٥] (٥)[7] ما يكون أكثر[8] من تمامه وأقل من الربع. فرضناه سبعين. فأجزاء [ج ٥٤ظ] المنطقة التي ميلها الشمالي عشرون أو أكثر أبدي الظهور. وهي[9] الجوزاء والسرطان. والتي ميلها الجنوبي كذا أبدي الخفاء. وهي القوس والجدي. والثمانية الأخر تطلع مع دورة المعدل.

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[1] (٤): الرابع [ف]

[2] مساويا: متساويا [ب]

[3] /على نقطة...مقابلهما: العبارة، في الهامش [ب]؛ مقابلهما: يقابلهما [أ، ب، ج، خ]

[4] رأس الجدي: العبارة، تحت السطر [ف]

[5] طلع: فأن طلع [ف]

[6] /فمن...المعدل: العبارة، شرح [ج]

[7] (٥): الخامس [ف]

[8] أكثر: +«القمر»، قبلها، ثم شطبت [ب]

[9] هي: هو [ب]

[24] [f. 58r] (4) (The fourth category of localities consists of) those whose (latitudes) are equal to the complement (of the obliquity of the ecliptic). The day circle of one of the two solstices is permanently visible. The pole of the ecliptic (also) passes through the zenith. Therefore, the cincture (of the ecliptic) coincides with the horizon, and the beginning of Cancer falls on the north point, while the beginning of Aries falls on the east point. The other two (opposite signs) [f. 58v] fall (on the points which are) diametrically opposite to these two (points). Thus, (the signs) between the beginning of Capricorn and the beginning of Cancer never rise in the eastern half of the horizon, whereas (the signs) between the beginning of Cancer and the beginning of Capricorn rise with (every) complete rotation of the equator.

[25] (5) (The fifth category comprises those localities) whose (latitudes) are greater than the complement (of the obliquity the ecliptic), and less than a (full) quadrant. Let us assume this (latitude) to be seventy (degrees). The portions of the ecliptic whose northern declination is equal to or greater than twenty (degrees) are permanently visible. These are Gemini and Cancer. Those (portions of the ecliptic) whose southerly declinations are the same are permanently invisible. These are Sagittarius and Capricorn. The remaining eight (signs) rise with the rotation of the equator.

[٢٦] ولقطب البروج مدار حول قطب العالم، تنصفه دائرة نصف النهار. ثم تقسم دائرة أول السموت كل نصف بقسمين: فالشماليان[١] متساويان،[٢] وكذا الجنوبيان. وكل من الأولين أعظم من كل من هذين. [ب ٢٣٣و] فمع قطع القطب كل قسم يطلع برجان. ففرضنا أولا قطب البروج على دائرة نصف النهار، /شمالا. [أ ٥٩و] فرأس السرطان في غاية ارتفاعه جنوبا، علي دائرة نصف النهار،[٣] ورأس الميزان على أفق المشرق. والآخران يقابلاهما.[٤] [ف ٣١١ظ] فيطلع الميزان والعقرب مستويين من نقطة المشرق إلى نقطة الجنوب. ورأس السرطان يتحرك إلى المغرب، وقطب البروج الظاهر إلى المشرق. [خ ٦٠ظ] فالحمل والثور غربا مستويين[٥] في هذا الزمان، من[٦] نقطة المغرب إلى نقطة الشمال. [هـ ٣٦ظ] وذلك لأن العقرب إذا طلع، كان رأس القوس على الأفق، في غاية الارتفاع، إذ لا طلوع له. وهي لا تكون إلا في نقطة الجنوب من دائرة الارتفاع. [ج ٥٥و] /فهو نقطة الجنوب. فرأس الجوزاء على نقطة الشمال.[٧] فمنه إلى رأس القوس يكون ظاهرا، غربيا، لأن القطب

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[١] فالشماليان: فالشماليان [ب]

[٢] متساويان: مساويان [ب]

[٣] /شمالا...النهار: العبارة، سقطت [ب، ج]

[٤] يقابلاهما: يقابلانهما [ف]

[٥] مستويين: مستويان [ب]

[٦] من: في [أ، ب، ج]

[٧] /فهو...الشمال: العبارة، شرح [ج]

[26] The pole of the ecliptic (also) traces a day circle around the pole of the world, which is bisected by the meridian circle. The prime vertical divides each (of the above two halves) into two parts: the two northerly parts are equal, and so are the two southerly ones. Moreover, each of the former is larger than each of the latter. Now as the pole moves through each of these sections, two signs will rise. Let us first assume that the pole of the ecliptic falls on the meridian circle, towards the north. [f. 59r] The beginning of Cancer is then at its maximum southerly altitude, on the meridian circle, whereas the beginning of Libra falls on the eastern horizon. The two other (opposite signs) fall (on the points which are) diametrically opposite to these two (points). Both Libra and Scorpio will then rise forward (as they move) from the east point towards the south point. The beginning of Cancer (also) moves towards the west, while the visible pole of the ecliptic (moves) to the east. (Moreover), during this same time, both Aries and Taurus will set forward, (as they move) from the west point to the north point. This is so because if Scorpio rises, then the beginning of Sagittarius falls on the horizon, and this will be the latter's maximum altitude, since it does not rise. It (i.e. the maximum altitude of the beginning of Sagittarius), however, can only fall on (the side of) the south point of the altitude circle. Therefore, (the beginning of Sagittarius) is itself the south point. The beginning of Gemini then falls on the north point, and (the portion of the ecliptic) between it and the beginning of Sagittarius will be visible on the western (horizon), since the pole (of the ecliptic) is

شرقي على دائرة أول السموت، [ب ٢٣٣ظ] ضرورة أن قطبيها على المنطقة. [ف ٢١٢و]

[٢٧] ولما كان هذا القسم من مدار القطب أعظم، كان طلوع الميزان [أ ٥٩ظ] والعقرب مع طلوع أكثر من ربع المعدل، لأن هذا المدار مواز للمعدل. وعند طلوع ربع المعدل، قد كان رأس الميزان على دائرة نصف النهار. ثم بعد ذلك يرتفع رأس الجوزاء /من أفق الشمال،[١] /فيطلع ما اتصل به،[٢] لا[٣] الطرف الآخر، لأنه أبدي الظهور. فيطلع الثور، [خ ٦١و] ثم الحمل معكوسين، من /نقطة الشمال إلى نقطة المشرق. / ويغرب العقرب، ثم الميزان معكوسين، من[٤] نقطة الجنوب إلى نقطة المغرب.[٥] فصار الحمل على نقطة المشرق، ورأس الميزان مقابله.[٦] ورأس السرطان على دائرة نصف النهار، شمالا، في غاية انحطاطه، مرتفعا من الأفق بقدر فضل الميل الكلي على تمام عرض البلد.

[٢٨] فالتوالي هنا من المشرق إلى المغرب. وقطب البروج على دائرة نصف [ج ٥٥ظ] النهار، جنوبا. بعده عن سمت الرأس كارتفاع رأس

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[١] /من...الشمال: العبارة، شرح

[٢] /فيطلع...به: العبارة، شرح [أ]

[٣] لا: لان، ثم شطبت أل ن [ب]

[٤] /نقطة الشمال...من: العبارة، سقطت [ب]

[٥] /ويغرب...المغرب: العبارة، سقطت [أ]

[٦] مقابله: يقابله [ب، ج]

easterly, (and it falls) on the prime vertical. (Moreover, the pole of the ecliptic falls on the prime vertical) because the latter's poles fall on the ecliptic.

[27] Now since the above portion of the day circle of the pole (of the ecliptic) is greater (than the following portion of the same circle), and because this day circle is parallel to the equator, therefore the rising of both Libra [f. 59v] and Scorpio corresponds to the rising of more than a quadrant of the equator. Also, as a quadrant of the equator rises, the beginning of Libra arrives at the meridian. Then, after that, the beginning of Gemini rises from the northern horizon, and what follows it will thus rise, instead of its own other end, because it (i.e. Gemini) is permanently visible. Taurus, and after it Aries, thus rise backwards, (as they move) from the north point to the east point. (On the other hand), Scorpio, and after it Libra, set backwards, (as they move) from the south point to the west point. (The beginning of) Aries then falls on the east point, while the beginning of Libra (falls) diametrically opposite to it. The beginning of Cancer falls on the (side of the) northern (point on the) meridian circle, at its lowest altitude, where its altitude above the horizon is equal to the difference between the obliquity of the ecliptic and the complement of the latitude of the locality.

[28] (The following) succession (in the motion of the pole of the ecliptic) at this point is from the east to the west. The pole of the ecliptic falls on the southern (part of the) meridian circle. Its distance from the zenith is equal to the latitude of the beginning

السرطان. فكان[1] طلوع الثور والحمل وغروب مقابلهما مع طلوع [ف ٣١٢ظ] أقل من ربع المعدل. إذ هنا قد طلع نصفه، وهو من الخريفية إلى الربيعية، وقد طلع أكثر من ربعه[2] مع الميزان والعقرب، فبقي الأقل مع هذين.

[٢٩] /ثم يطلع رأس الحمل، وما يتصل به تحت الأرض، وهو آخر [هـ ٣٧و] الحوت، معكوسا أيضا من نقطة المشرق إلى نقطة الجنوب. ويغرب بأزائه رأس الميزان، [ب ٢٣٤و] ثم ما يتصل به فوق الأرض، وهو آخر السنبلة إلى رأس الأسد، معكوسا من نقطة المغرب إلى نقطة الشمال. فصار رأس الأسد على نقطة الشمال، ورأس الدلو على نقطة الجنوب. والنصف [أ ٦٠و] الظاهر من البروج شرقي، وقطب البروج على دائرة أول السموت غربي.[3] [خ ٦١ظ] /وهذان البرجان طلعا مع أقل من ربع المعدل.

[٣٠] ثم يطلع من رأس الأسد إلى رأس الميزان، من نقطة الشمال إلى نقطة المشرق، مستويا، ويغرب من رأس الدلو إلى رأس الحمل، من نقطة الجنوب إلى نقطة المغرب، مستويا، مع أكثر من ربع المعدل. فتم الدور، وصار كما كان.

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[1] فكان: وكان [أ، ب]

[2] ربعه: ربع [ج]

[3] /ثم...غربي: العبارة، شرح [أ، ب]

of Cancer. The rising of both Taurus and Aries, and the setting of the (two signs which are) diametrically opposite to them, thus correspond to the rising of less than a quadrant of the equator. (The above is true because) at this point half (the equator) has risen, namely (the portion) between the autumnal and the vernal (equinoxes), while more than a quadrant has (also) risen with the (corresponding rise) of Libra and Scorpio. Therefore, less (than a quadrant of the equator) corresponds to these two (signs, Aries and Taurus).

[29] Next, the beginning of Aries, together with what follows below (the horizon of) the earth, namely the end of Pisces, also rise backwards (while moving) from the east point to the south point. On the other side, the beginning of Libra, together with what follows above (the horizon of) the earth, namely the end of Virgo to the beginning of Leo, set backwards (while moving) from the west point to the north point. The beginning of Leo thus falls on the north point, while the beginning of Aquarius (falls) on the south point. The visible half [f. 60r] of the ecliptic is then easterly, and the pole of the ecliptic (falls) on the western (part of the) prime vertical. (Moreover), the rising of the above two signs corresponds to (the rising of) less than a quadrant of the equator.

[30] Next, (the signs) between the beginning of Leo and the beginning of Libra rise forward, (as they move) from the north point to the east point, and (the signs) between the beginning of Aquarius and the beginning of Aries set (as they move) from the south point to the west point. (The above rising and setting) corresponds to (the rising) of more than a quadrant of the equator. One whole revolution is thus completed, and the initial (position) will be reproduced.

[٣١] /فظهر أن أربعة[١] بروج، وهي[٢] من رأس الأسد إلى رأس القوس، طلعت مستوية وغربت معكوسة، وأربعة[٣] أخرى، وهي من رأس الدلو إلى رأس الجوزاء، طلعت معكوسة وغربت مستوية. وزمان طلوع المستويات وغروبها أكثر من زمان طلوع المعكوسات وغروبها.[٤]

[٣٢] (٦) ما يكون ربع الدور. فقطبا المعدل على سمت الرأس والقدم، [ف ٣١٣و] وهو منطبق على الأفق. فالدور رحوي. ونصف المنطقة الشمالي أبدي الظهور، ومقابله أبدي الخفاء. فمدة كون الشمس في النصف الظاهر نهار. ففضل النهار على الليل بسبب[٥] البطء في النصف الأوجي، [ج ٥٦و] وهو تسعة أيام من أيامنا.

[٣٣] ولكون دائرة الميل دائرة الارتفاع، يكون ارتفاع أجزاء البروج وانحطاطها بقدر الميل.

[٣٤] [ب ٢٣٤ظ، خ ٦٢و] /ويكون الصبح والشفق في قريب خمسين يوما من أيامنا، لأن الشمس فيها تقطع خمسين درجة[٦] [أ ٦٠ظ] من نقطة الاعتدال. وميلها يح درجة.والقوس التي بين الشمس

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[١] أربعة: أربع [ج]

[٢] وهي: وهو [أ، ب، ج]

[٣] أربعة: أربع [ج]

[٤] /وهذان...وغروبها: العبارة، شرح [أ]؛ /فظهر...غروبها: العبارة، شرح [ج]

[٥] بسبب: سبب [أ، ب]

[٦] /ويكون...درجة: العبارة، شرح [أ]

[31] It is, therefore, evident that four signs, namely from the beginning of Leo to the beginning of Sagittarius, rise forward and set backwards, while four other (signs), namely from the beginning of Aquarius to the beginning of Gemini, will backwards and set forwards. (Moreover), the time for the forward rising and setting is greater than the time for the backward rising and setting.

[32] (6) (The sixth category of localities consists of) those whose (latitudes) are equal to a quadrant. The two poles of the equator then fall on the zenith and nadir, while it (the equator) coincides with the horizon. The (daily) rotation (of the sun) is like a millstone. The northern part of the ecliptic is permanently visible, while the opposite (half) is permanently invisible. (Moreover), the period when the sun is in the visible part is the daytime. Therefore, the increase of the daytime over the nighttime results from slowness (of the motion of the sun) in the apogee half, and this is nine days of our days.

[33] Because (in the above case) a declination circle is an altitude circle, the altitudes and depressions of the points of the ecliptic are equal to their declinations.

[34] Dawn and twilight last about fifty days of our days, because during these (days) the sun travels through fifty degrees [f. 60v] away from the vernal equinox. Its declination is thus 18 degrees, and if the arc between the sun

والأفق من دائرة الارتفاع، إذا كانت يح درجة، يظهران.

[٣٥] ولايكون للكوكب طلوع وغروب بالحركة الأولى بل بالثانية، والمشرق متميز عن المغرب في تلك لا في هذه. فالكوكب إذا انتقل إلى الحمل، في أي موضع من الأفق يصير /طالعا، وإلى الميزان كذا، يصير[١] غاربا.

[٣٦] ثم كل كوكب لا عرض له ففي نصف الدور [هـ ٣٧ظ] ظاهر. وماله عرض في جهة القطب الظاهر، فأن كان أقل من الميل الكلي، فظهوره أكثر من خفائه. وإلا فأبدي الظهور. وماله عرض بخلافه، فأن كان أقل مما ذكر فخفاؤه [ف ٣١٣ظ] أكثر، وإلا فأبدي الخفاء.

[١] /طالعا...يصير: العبارة، سقطت، وأضيفت في الهامش [ب]؛ يصير: الكلمة، شرح [ب، هـ]

and the horizon (which is measured) along the altitude circle is 18 degrees, then they (i.e. the twilight and the dawn) are visible.

[35] A star rises or sets as a result of the first motion, rather than the second, while an eastern (star) is distinguished from a western one by the former rather than the latter. Thus, if a star moves into Aries at any position on the horizon, then it becomes a rising (star), while if (it moves) into Libra in the same manner, then it becomes a setting (star).

[36] Moreover, every star which has no latitude is visible through one half of a revolution (of the ecliptic). If (the star) has a latitude on the side of the visible pole (of the ecliptic), and if (this latitude) is less than the obliquity of the ecliptic, then its visibility is longer than its invisibility; otherwise, (the star) is permanently visible. (In the case of those stars) which have a latitude in the opposite direction, if (this latitude) is less than the above mentioned value, then its invisibility is longer (than its visibility); otherwise, (the star) is permanently invisible.

[١] [ج ٥٦ظ] فصل: في المطالع والممر.

[٢] كل قوس من منطقة البروج يطلع مع قوس من المعدل، فتلك درج السواء، وهذه مطالعها.

[٣] [خ ٦٢ظ] ففي خط الاستواء، الربع الذي من الاعتدال إلى الانقلاب يطلع مع الربع، لأنه إذا طلع ذلك الربع، تكون نقطة الاعتدال على سمت الرأس. فالمعدل والمنطقة مرا على قطبي الأفق، فالأفق يمر على أقطابهما، فيقطعهما على زوايا قائمة. [أ ٦١و] والربع بالعكس كذا. [ب ٢٣٥و] /لأن النهاية واحدة.[١]

[٤] /ثم من نقطة[٢] الاعتدال /إلى أقل من الربع أكثر من مطالعه، لأن المطالع قائمة على الأفق، فدرج السواء وتر القائمة. [ف ٣١٤و] فالباقي إلى الانقلاب أقل من المطالع.[٣] /ثم من نقطة الانقلاب[٤] إلى أقل من الربع أقل من المطالع،[٥] لأن الباقي إلى الاعتدال، تحت الأرض، أكثر من مطالعه، لأنه وتر قائمة في مثلث تحت الأرض. ووتر القائمة

[١] /لأن...واحدة: العبارة، شرح [أ، ب]

[٢] نقطة: منطقة [ف]

[٣] /ثم...المطالع: العبارة، تكررت [ب]

[٤] /إلى أقل...نقطة الانقلاب: العبارة، شرح [أ]

[٥] /ثم...المطالع: العبارة، سقطت [ج]

[1] Chapter [15]: On Ascensions and Transits.

[2] Every arc on the cincture of the ecliptic rises with an arc of the equator. That (arc) is called equal degrees, and these (degrees) are their ascensions.

[3] On the (terrestrial) equator, the quadrant which falls between the equinoctial (point) and the solstice rises with the (corresponding) quadrant (of the ecliptic), because when the former quadrant rises, the equinoctial point falls on the zenith. The ecliptic and the equator then pass through the two poles of the horizon, and the horizon also passes through their poles, and intersects them at right angles. [f. 61r] (Moreover), the quadrant (of the ecliptic) which is opposite (the above one) is similar to it, because (in both cases,) the end point (of the two quadrants) is one.

[4] Next, (arcs of the ecliptic which are) less than a quadrant away from the equinoctial point are greater than their ascensions, because the ascensions are perpendicular to the horizon, and an arc of the ecliptic is thus the hypotenuse of the right angle. The remaining parts (of the ecliptic) to the solstices are therefore less than their ascensions. Moreover, (arcs of the ecliptic which are) less than a quadrant away from the solstice are less than their ascensions, because the remaining parts (of the ecliptic) to the equinoctial (point), below (the horizon of) the earth, are greater than their ascensions, the former being the hypotenuse of a (spherical) triangle below (the horizon of) the earth. The hypotenuse of a right angle is

أعظم، إلا[1] أن يكون في الكرة ربع الدور، فأنه مساو[2] للضلع[3] الآخر، الذي هو ربع الدور.

[٥] فظهر أن كل ربع مشتمل على نقطة الاعتدال أكثر من مطالعه، وعلى الانقلاب أقل. وكل قوسين متساويتين، متساويتي[4] البعد عن إحدى النقط الأربع، فمطالعهما[5] متساوية.

[٦] [خ ٦٣و] ودائرة نصف نهار كل بقعة[6] أفق من آفاق الاستواء. فمرور المنطقة والمعدل عليها كالطلوع في خط الاستواء. [ج ٥٧و، هـ ٣٨و] وكذا حكم دوائر الميل. والمغارب كالمطالع. [أ ٦١ظ]

[٧] وأما في الآفاق المائلة، فيطلع كل نصف [ف ٣١٤ظ] بين الاعتدالين مع النصف، لا ربع مع ربع. وإذا فرض مثلث فوق الأرض رأسه أحد الاعتدالين. فدرج السواء، إن كانت في جانب القطب الظاهر، فهي أعظم من المطالع، لأن تلك وتر المنفرجة، وهذه وتر الحادة. فالباقي [ب ٢٣٥ظ] إلى النصف أقل من مطالعه. وإن كانت في الجانب الآخر فهي أقل منها، فالباقي إلى النصف أعظم منها.

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[1] إلا: لا [أ]

[2] مساو: مساوي [أ]، يساوي [ب]

[3] للضلع: الضلع [ب]

[4] متساويتين، متساويتي: متساويين، متساوي [أ، ب]

[5] فمطالعهما: فمطالعها [أ، ب]

[6] بقعة: نقطة [خ]

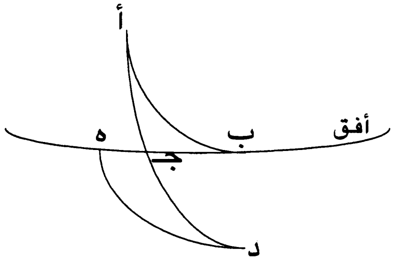
greater (than the other sides of a right angle triangle), except in a sphere where it is (equal to) a quadrant, in which case it could be equal to the other side (of the spherical triangle), which is itself equal to a quadrant.

[5] It is thus clear that every quadrant which incorporates the equinoctial point is greater than its ascension, while (a quadrant incorporating) the solstice is less. Moreover, the ascensions of any two equal arcs, which are equidistant from one of the four points (i.e. the solstices and the equinoxes), are equal.

[6] The meridian of any locality is one of the horizons of the equator. The transit of the ecliptic and the equator through it (i.e. the meridian) is thus similar to the ascension at the equator. The same rule applies for the declination circles. (Moreover), descensions are similar to ascensions.

[7] [f. 61v] In the case of inclined horizons, one half (of the ecliptic falling) between the two equinoxes ascends with (the corresponding) half (of the equator), rather than a quadrant with a quadrant. (Now), consider a (spherical) triangle above (the horizon of) the earth, such that its vertex is one of the two equinoxes: if the arc of the ecliptic is on the side of the visible pole, then it is greater than its ascension, because the former is subtended by an (obtuse) angle, while the latter is subtended by an acute one. The remaining part of half (the ecliptic) is thus less than its ascension. If (the arc of the ecliptic) is on the other side, then it is less (than its ascension), and the remaining part of the half is greater (than its ascension).

[٨] [ج ٥٧ظ، خ ٦٣ظ] وكل قـوسين مـتـسـاويـتين،[١] على جنبـتي اعتدال، متساويتي البعد عنه، فمطالعهما متساويتان، كمطالع الحوت للحمل، والثور للدلو، وهكذا. /لأنه إذا كان رأس الحمل فوق الأرض، وهو نقطة أ، ومنه إلى الأفق من درج السـواء أ ب، ومطالعـهـا أ جـ، فحصل مثلث أ ب جـ، وقوس ب جـ قوس من الأفق. ثم فرضنا رأس الحمل تحت الأرض، ومنه إلى الأفق من درج السواء ه د مساوية لقوس أب، لكن ه د جنوبي، وأ ب شـمـالي،[٢] [أ ٦٢و، ف ٣١٥و] وإذا طلع ه د يطلع معه من المعدل جـ د. فهذا مطالع[٣] ذلك.



شكل ٨٤

[٩] ولنتصور من هذا الشكل المشتمل على الخطوط المستقيمة، وهي

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[١] متساويتين: متساوي [أ، ب]

[٢] /لأنه...شمالي: العبارة، شرح [أ]

[٣] مطالع: وطالع [ج]

[8] The ascensions of any two equal arcs, which fall on the two sides of an equinox and are equidistant from it, are equal, as are the ascensions of Pisces (equal) to those of Aries, and Taurus to Aquarius, and so on. (This is true) because: if the beginning of Aries is above (the horizon of) the earth, namely point *A*, and if (the distance) from it to the horizon along the ecliptic is *AB*, while the ascension (of this latter arc) is *AG*, then a triangle *ABG* is produced, such that arc *BG* is an arc on the horizon. If next we assume that the beginning of Aries is below (the horizon of) the earth, and that (the distance) from it to the horizon along the ecliptic is (an arc) *ED* which is equal to arc *AB*, such that *ED* is southerly, while *AB* is northerly, [f. 62r] then if *ED* ascends, *GD* of the equator ascends with it. (Moreover), the latter (ascension) is (equal to) the ascension of the former.

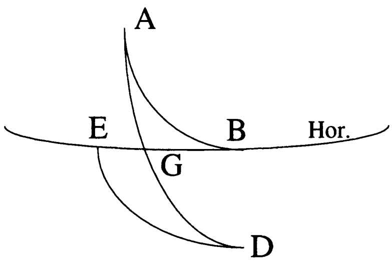

FIGURE 84

[9] Let us imagine from the above the diagram incorporating straight lines which are

للاوتار[١] قسيها على الكرة، على أن ه جـ وتر قوس من دائرة الأفق، وكذا جـ ب، ونقطة جـ مطلع معدل النهار. فالمطلوب أن أ جـ يساوي[٢] دجـ. لأن زاوية أ تساوي[٣] زاوية د،[٤] وزاوية أ جـ ب تساوي[٥] زاوية ه جـ د،[٦] لأنهما متقابلتان. وضلع أ ب يساوي ضلع ده. فضلع أ جـ يساوي [هـ ٣٨ظ] د جـ، وإلا فإن كان أحدهما زائدا، وليكن الزائد أجـ، فيفضل [ب ٢٣٦و] عنه مقدار د جـ، وهو أ ط. ونصل ط ب. فلأن زاوية أ تساوي زاوية د، وخط أ ب يساوي ده، فإن ساوى أ ط خط دجـ،[٧] كان الزوايا الباقية مساوية[٨] كل لنظيرتها. فزاوية أ ط ب [خ ٦٤و] مساوية لزاوية[٩] د جـ ه،[١٠] /وهو محال لأن زاوية د جـ ه مساوية لزاوية أ جـ ب، /فتكون زاوية أ ط ب مساوية لزاوية أ جـ

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[١] للأوتار: الأوتار [ب، ج]

[٢] يساوي: الكلمة، تكررت [ج]، مساوي [ب]

[٣] تساوي: مساوية [هـ]

[٤] د: الكلمة، سقطت [ج]

[٥] تساوي: مساوي [ب]

[٦] ه جـ د: جـ د [ج]

[٧] دجـ: دجـ ب [ج]

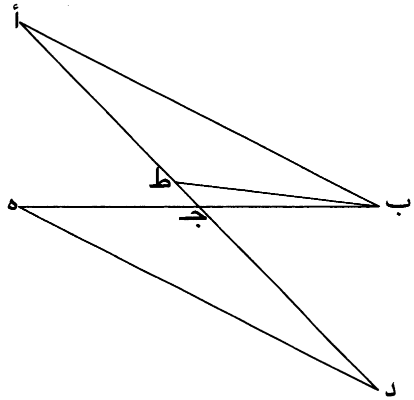
[٨] مساوية: متساوية [ج]

[٩] لزاوية: +«أدب، فتكون زاوية أط ب مساوية لزاوية أجـ ب»، بعدها، ثم شطبت [ب]

[١٠] دجـ ه: الكلمة، في الهامش [ب]

the chords of the arcs on the sphere, such that *EG* is the chord of an arc on the horizon, and so is *GB*, and point *G* is the ascension of the equator. It is required (to prove) that *AG* equals *DG*. (Now), angle *A* equals angle *D*, and angle *AGB* equals *EGD*, since these are opposite (angles). (Moreover), side *AB* equals side *DE*. Therefore, side *AG* equals *DG*. Otherwise, if one (of the latter two sides) is greater than the other, and assuming that this greater one is *AG*, then it will exceed the length of *DG*, say by *AT*. We then join *TB*. (Now), angle *A* equals angle *D*, and line *AB* equals *DE*. If then *AT* were equal to line DG, then each of the corresponding remaining angles would be equal. Angle *ATB* would thus be equal to angle *DGE*, which is impossible because angle *DGE* is equal to angle *AGB*, which would mean that angle *ATB* is equal to angle *AGB*,

ب،[1] وهو محال لأنها خارجة عن مثلث ب ط جـ، والخارجة أعظم من كل من الداخلتين المقابلتين لها.



شكل ٨٥

[١٠] فإن قلت: لا نسلم هذا في الكرة، قلت: بحثنا فيما إذا كان الضلع أصغر من ربع دور الكرة، فإن البرهان يتم حينئذ، لا إن كان ربعا. فإن أ ط ب[2] أعظم من زاوية ب جـ ط. [ف ٣١٥ظ] فنخرج ب ط[3] إلى س، وننصف[4] ط جـ على نقطة ع.[5] ونصل ب ع[6] ونخرجه إلى

---

[1] /فتكون...أ جـ ب: العبارة، سقطت [ج]

[2] أ ط ب: أطرب [ف]

[3] ب ط: بط [ج]

[4] ننصف: ينتصف [ج]

[5] نقطة ع: نقطتي عن [ب]

[6] ب ع: ب جـ [ب]، ع [ج]

which is (in turn) impossible since the former (angle) is exterior to triangle *BTG*, and an exterior angle is greater than either one of the opposite interior ones.

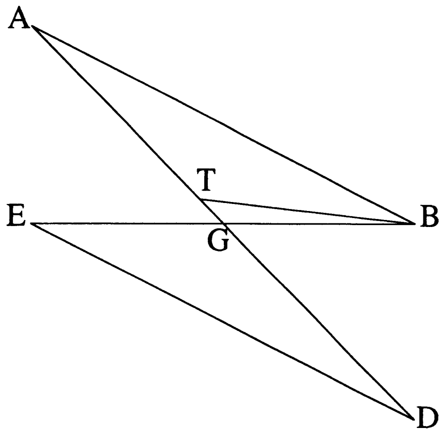
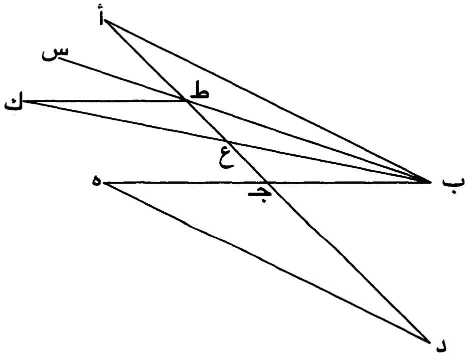


FIGURE 85

[10] If next it is maintained that the above is not granted in the case of a sphere, then I say (in response) that we have discussed (the case) when the side is less than a quadrant of the sphere; the proof only holds in that case, and not when it is a quadrant. For (angle) *ATB* is greater than angle *BGT*. (To illustrate this) let us extend *BT* to *S*, and bisect *TG* at point *O*. Join *BO* and extend it to

نقطة ك، ونجعل ك ع [ج ٥٨و] مساويا لخط ب ع. /ونصل ك ط. ففي مثلثي ب ع جـ و ك ع ط، ضلع جـ ع[١] مساو لضلع ط ع،[٢] وضلع ك ع مساو لضلع ع ب. وزاوية ب ع جـ مساوية لزاوية ط ع ك لكونهما متقابلتين. فالمثلث مساو للمثلث، وسائر الزوايا لسائر الزوايا، كل لنظيرتها. فزاوية ب جـ ع مساوية لزاوية ك ط ع، التي هي بعض [أ ٦٢ظ] زاوية س ط جـ،[٣] المساوية لزاوية أ ط ب، لأنهما متقابلتان.[٤] فزاوية ب جـ ط[٥] أصغر من ب ط أ الخارجة،[٦] فهذه أعظم من تلك بهذه الصورة.



شكل ٨٦

[١] جـ ع: دع [ب]

[٢] /ونصل...ط ع: العبارة، سقطت وأضيفت «نصل» في الهامش [ج]

[٣] س ط جـ: س ذ ك جـ، ثم شطبت ال ك [ب]

[٤] متقابلتان: متقابلان[ج]

[٥] ب جـ ط: ب د ط [ب]

[٦] الخارجة: الخارج [ج]

point K, such that KO is equal to BO. (Also) join KT. Now in triangles BOG and KOT, side GO is equal to side TO, and side KO is equal to side OB. Angles BOG and TOK are equal because they are opposite (angles). The one triangle is thus equal to the other, and the remaining (two) angles (of the first triangle) are equal to the remaining angles (of the other triangle), each angle being equal to its opposite. Angle BGO is equal to angle KTO. (The latter) is only a part of [f. 62v] angle STG, which is (in turn) equal to angle ATB, since these two (last angles) are opposite. Therefore, BGT is less than the exterior (angle) BTA, and accordingly, the latter is greater than the former.

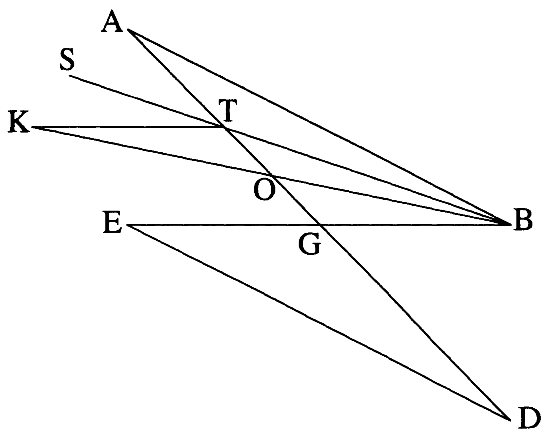
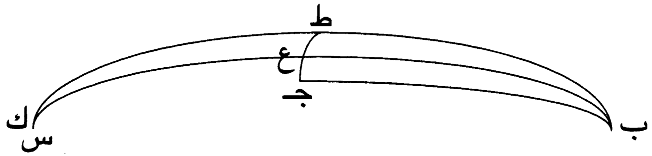


FIGURE 86

[١١] هذا[١] إذا لم يكن الضلع ربع الدور. أما إذا كان،[٢] فخط ب ط إن كان ربع الدور، ونقطة ب قطبا، وخط ط جـ قوسا من المنطقة، فخط ب جـ ربع الدور أيضا. فأذا أخرجنا في الطرف الآخر ع ك مساويا لخط ب ع،[٣] وصل [خ ٦٤ظ] إلى القطب الآخر. فأذا وصلنا ط ك،[٤] لم يقسم هذا الخط زاوية س ط جـ، لأن خط ك ط يكون منطبقا على خط س ط، لأن خط ب ط قائم على المنطقة، لخروجه من القطب. فأذا[٥] أخرج[٦] [ف ٣١٦و] في الطرف الآخر، يصل إلى القطب، فيكون منطبقا على خط[٧] ط ك.



شكل ٨٧

[١] هذا: هذ هذا [ج]
[٢] /وهو...كان: العبارة، شرح [أ]
[٣] ب ع: ع [ج]
[٤] ط ك: ط ط ك [ج]
[٥] فأذا: ف إذا [ج]
[٦] أخرج: خرج [أ، ب]
[٧] خط: الكلمة، سقطت [ج]

[11] The above holds if no side (of the spherical triangle) is a quadrant. If, however, (one of the sides) is, then let line *BT* be a quadrant, and let point *B* be a pole (of the ecliptic). Now line *TG* is an arc on the ecliptic, therefore, line *BG* is a quadrant too. If we mark *OK* on the other side (of *BO*), such that it is equal to line *BO*, then it (i.e. point *K*) reaches the other pole. If then we join *TK*, then this line does not bisect angle *STG*, because line *KT* coincides with line *ST*, since line *BT* is perpendicular to the ecliptic, being itself issued from the pole (of the ecliptic). If (a line is) issued (from point *T*) in the other direction, then it reaches the pole, and it coincides with line *TK*.

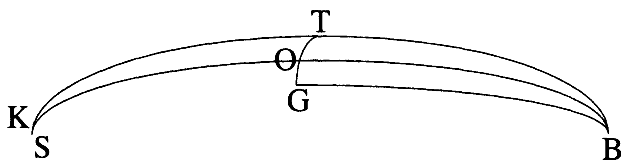


FIGURE 87

[١٢] فإذا كان مطالع أ ب مساوية لمطالع ده، فإن فضل من قوس أب قوس أط، ومن قوس ده قوس ز د [١] مساوية [ب ٢٣٦ظ] لقوس أط، فمطالعهما [هـ ٣٩و] متساويتان لذلك البرهان. فمطالع الباقي من كل متساوية.

[١٣] ثم المنطقة تنقسم قسمين: أحدهما ما يتوسطه الاعتدال الذي إذا جاوزه الكوكب وقع في جهة القطب الظاهر. فهو أعظم من مطالعه. والآخر مقابله، وهو أصغر من مطالعه. ومطالع القسي الشمالية في الآفاق الشمالية، كمطالع نظيرها من الجنوبية في الآفاق الجنوبية. وكذا مطالع الجنوبية. [ج ٥٨ظ] ومطالع كل قوس في كل أفق كمغارب نظيرها. [أ ٦٣و]

[١٤] وقد عرفت في القسم الرابع أن مطالع النصف من المنطقة كل معدل النهار. فهو مغارب نظيره. [ف ٣١٦ظ] /ولا مطالع لنظيره، لأنه يطلع في آن. فلا مغارب لذلك النصف لغروبه في آن.[٢]

[١٥] /وعرفت المطالع في القسم الخامس،[٣] فلا نعيدها.[٤]

[١٦] وأما المر على دائرة نصف النهار، فما [خ ٦٥و] لا عرض له ظاهر. /وما له عرض، فما يمر عليها حال كون[٥] قطبي البروج عليها،

---

[١] زد: زط [ج]، غير واضحة [أ، ب]

[٢] /ولا...في آن: العبارة، شرح [أ، ج]

[٣] /وعرفت...الخامس: العبارة، شرح [أ]

[٤] فلا نعيدها: العبارة، شرح [ج]

[٥] كون: الكلمة، سقطت [أ، ب]

[12] Let the ascension of an arc AB be equal to the ascension of an arc DE. If arc AB is reduced by arc AT, while arc DE is reduced by arc ZD which is equal to AT, then, according to the above proof, the ascensions of these (last two arcs) are equal. Therefore, the ascensions of the remainders from (the subtractions) are also equal.

[13] Next, the ecliptic is divided into two parts: the middle point of the first (part) is the equinoctial point, such that, if a star crosses (this point), it (i.e. the star) falls on the side of the visible pole. It (i.e. this part of the ecliptic) is greater than its ascensions. The other part (of the ecliptic) is diametrically opposite (the first part), and it is less than its ascensions. (On the other hand), the ascensions of northern arcs in the northern horizons, are equal to the ascensions of the opposite southern arcs in the southern horizons. Similarly, for the ascensions of the southerly (arcs in the northern horizons). (Moreover), the ascension of any arc in any horizon is equal to the descension of its opposite.

[14] [f. 63r] It has already been mentioned in the fourth category, (where the latitude of the locality is equal to the complement of the obliquity of the ecliptic), that the ascension of one half of the ecliptic is the whole of the equator. The latter is thus the descension of its opposite (i.e. of the other half of the ecliptic). (Moreover), this opposite has no ascension, because it ascends in no time. Therefore, the former half (of the ecliptic) has no descension, because it descends in no time.

[15] The ascensions of the fifth category, (where the latitude of the locality is greater than the obliquity of the ecliptic, and less than a quadrant), were also mentioned, so we will not repeat them (here).

[16] As for the transit of the meridian, it is visible in the case (of a star) which has no latitude. In the case of (a star) which has a latitude, if it (i.e. the star) transits (the meridian) while the two poles of the ecliptic fall on it (the meridian), then (the star)

يمر مع درجته.[١] وما يمر عليها حال كون القطب الذي هو[٢] في جهته شرقيا، يمر بعد درجته. لأن دائرة العرض [ب ٢٣٧و] إذا أخرجت من القطب الشرقي إلى الكوكب، وإلى درجته، وهي على دائرة نصف النهار، فالكوكب شرقي عنها،[٣] لأنه أقرب إلى القطب من درجته. فيمر بعد درجته. وما يمر حال كون ذلك القطب غربيا، يمر عليها قبل درجته. لأن الدائرة إذا أخرجت منه، [ج ٥٩و] إلى الكوكب، وإلى درجته، وهي على دائرة نصف النهار، فالكوكب غربي عنها حينئذ. فمروره كان من قبل.

[١٧] /ثم اعلم أن قطب العالم الظاهر إن كان الشمالي، فقطب البروج الظاهر إن كان شرقيا، [أ ٦٣ظ] طلع النصف الجنوبي، ويمر ما يتوسطه الخريفي.[٤] [خ ٦٥ظ، ف ٣١٧و، هـ ٣٩ظ] وإن كان غربيا، يطلع ويمر ما يقابلهما.[٥] وإن كان هو الجنوبي، فهذا إن كان شرقيا،[٦] يطلع النصف الشمالي، ويمر ما يتوسطه الربيعي. وإن كان غربيا، يطلع ويمر مقابلهما.[٧]

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[١] /وما...درجته: العبارة، شرح [ج]

[٢] هو: هي [ج]

[٣] عنها: الكلمة، سقطت [ج]

[٤] /ثم...الخريفي: العبارة، شرح [أ، ج]

[٥] يقابلهما: على يقابلهما، ثم شطبت على [ج]، يقابلها [أ، ب]

[٦] شرقيا: مشرقيا [ب]

[٧] مقابلهما: مقابلها [أ، ب]

transits with its (longitude) degree. If (the star) transits (the meridian) when the pole (of the ecliptic) on whose side (this star) falls is easterly, then (the star) transits after its (longitude) degree. (This is true) because, if a latitude circle is issued from the eastern pole to the star, and if (another latitude circle is issued) to the degree (of the star) while it falls on the meridian, then the star is east of it (i.e. the meridian), being closer to the pole than its own degree. Therefore, (the star) transits after its degree. If (the star) transits while the above pole is westerly, then (this star) transits before its degree. (This is true) because, if (latitude) circles are issued from it (the pole) to the star, and to its degree while it falls on the meridian, then, in that case, the star is west (of the meridian). Therefore, (the star) transits before (its degree).

[17] Next, note that if the visible pole of the world is the northern one, and if the visible pole of the ecliptic is easterly, [f. 63v] then the southern half (of the ecliptic) ascends, and the part (of the ecliptic) whose midpoint is the autumnal (equinox) culminates. If (the pole of the ecliptic is) westerly, then the opposite (parts of the ecliptic) ascend and culminate. (On the other hand), if it (the visible pole of the world) is the southerly one, and if the latter (pole of the ecliptic) is easterly, then the northern half (of the ecliptic) ascends, and the part (of the ecliptic) whose midpoint is the vernal (equinox) culminates. If (the pole of the ecliptic is) westerly, then the opposite parts of the ecliptic ascend and culminate.

[١٨] والطلوع والغروب في الاستواء كالمرور في غيره. فما يطلع حال كون قطبي البروج على الأفق، يطلع مع درجته. وكذا الغروب. وما يطلع /حال كون القطب الذي في جهته خفيا، يطلع بعد درجته. وما يطلع[١] حال كونه ظاهرا، يطلع قبلها. فإن الخفاء كالشرقية، إذ[٢] طلوع الخفي كمرور الشرقي. وحكم الغروب على العكس. لأن دائرة العرض إن أخرجت من القطب الخفي إلى الكوكب، وإلى درجته، وهي على الأفق، فقد وصلت[٣] إليه[٤] تحت الأفق. فإن كان أفق الشرق، فالكوكب لم يطلع بعد. وإن كان أفق الغرب، [ب٢٣٧ظ] فهو قد غرب. وإن أخرج[٥] دائرة العرض من القطب الظاهر إليه، وإلى درجته، وهي على الأفق، فقد وصلت إليه فوق الأفق. ففي الشرق قد طلع، وفي الغرب لم يغرب بعد. وكذا في الآفاق المائلة.

[١٩] ثم ما طلع قبل درجته، [ف ٣١٧ظ] أو بعدها، في الاستواء، يغرب كذا، لتساوي قوس [ج ٥٩ظ] النهار والليل للكوكب ودرجته. فإذا طلع حال ظهور القطب الذي هو في [أ ٦٤و] جهته، يغرب حال

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[١] /حال...ما يطلع: العبارة، في الهامش [ج]

[٢] إذ: أو [ج]

[٣] وصلت: وصل [أ، ب، ج]

[٤] إليه: +«وإلى درجته»، ثم شطبت [ب]

[٥] أخرج: خرج [أ، ب]

[18] The descension and ascension (of stars for localities at the terrestrial) equator is similar to the transit at other (localities). (A star) which ascends when the two poles of the ecliptic fall on the horizon ascends with its degree. Similarly, for the descension. (A star) which ascends while the pole (of the ecliptic) on whose side (this star) falls is invisible, ascends after its degree. (A star) which ascends while (the above pole) is visible, ascends before its (degree). Being invisible will then be similar to being easterly, since the ascension of the invisible is similar to the culmination of the easterly. The rule for the descension is the converse (of the rule for the ascension). (The above is true) because if latitude circles are issued from the invisible pole (of the ecliptic) to the star, and to its degree while it falls on the horizon, then it (i.e. the latitude circle) reaches (the star) while it is below the horizon. If this is the eastern horizon, then the star would not have ascended yet. If it is the western horizon, then it would have descended. (On the other hand), if the latitude circles are issued from the visible pole to it (i.e. the star), and to its degree while it falls on the horizon, then it reaches (the star) while it is above the horizon. (The star) would thus have ascended in the east(ern horizon), and it would not have descended in the western one. Similarly, for the inclined horizons.

[19] Next, (a star) which ascends before or after its degree at the equator, will descend in a similar manner, because the arcs of day and of night of the star are equal, and so will those of the degree (of the star). (Moreover), if (a star) ascends while the pole (of the ecliptic) on whose side it falls is visible, [f. 64r] then (this star) descends while (the pole) is

خفائه.[١] وإن طلع حال خفائه،[٢] يغرب حال ظهوره.

[٢٠] بخلاف الآفاق المائلة: فأن عرضها، إن كان أكثر من الميل الكلي، فأحد قطبي البروج ظاهر دائما.[٣] وكل كوكب عرضه في جهته يطلع قبل درجته ويغرب بعدها. وما بخلافه، فبالخلاف. [خ ٦٦و] وإن كان أقل، فما يطلع ويغرب حال ظهور قطب هو في جهته، فكذا.[٤] وحال خفائه، فبالعكس.

[٢١] ثم في خط الاستواء، قطب البروج الشمالي ظاهر حال طلوع نصف يتوسطه الربيعي، ومرور النصف[٥] الجنوبي فوق. والجنوبي ظاهر حال الطلوع، والمرور بمقابلهما.[٦]

[٢٢] [هـ ٤٠و] وفي التحفة «أن درجة طلوع الكوكب، إن كان بين درجة الشمس ونظيرها، يطلع نهارا. وإن كان بين نظيرها ودرجتها، يطلع ليلا. ودرجة الغروب، إن كان بين الأولين، يغرب ليلا. وإن كان بين الأخيرين، يغرب نهارا.» وإنما قال درجة [ف ٣١٨و] طلوع الكوكب، ولم يقل درجة الكوكب، لأنه قد يطلع قبل درجته أو بعدها.

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[١] خفائه: الكلمة، أضيفت فوق السطر [أ]، وفي الهامش [ب]

[٢] حال خفائه: العبارة، تكررت [ب]

[٣] ظاهر دائما: العبارة، سقطت [أ، ب، خ]، وأضيفت في الهامش [أ]، أبدي الظهور [ج]

[٤] فكذا: كذ فهكذا، ثم شطبت كذ [ج]

[٥] النصف: نصف [ج]

[٦] بمقابلهما: لمقابلهما [ج]

invisible. If (the star) ascends while (the pole) is invisible, then it descends while (this pole) is visible.

[20] The above is contrary to the (case of the) inclined horizons: if the latitude (of the locality) is greater than the obliquity of the ecliptic, then one of the two poles of the ecliptic is permanently visible. A star whose latitude is on the side of this (visible pole) ascends before its degree, and descends after it. The converse (is true) in the case of (a star whose latitude is) opposite (to the above). If, (on the other hand), it (i.e. the latitude of the locality) is less (than the obliquity of the ecliptic), then a star which ascends and descends while the pole (of the ecliptic) on whose side (this star) falls is visible will be the same (as above). The converse (is true if the pole) were invisible.

[21] Next, at the terrestrial equator, the northern pole of the ecliptic is visible during the ascension of the half (of the ecliptic) whose midpoint is the vernal (equinox), and during the transit of the southern half (of the ecliptic) through the (part of the meridian which is) above (the horizon). The southern (pole of the ecliptic) is visible during the opposite ascension and transit.

[22] In the *Tuḥfa* (it is stated that): "if the degree of ascension of the star falls between the degree of the sun and the point symmetrical with it, then (the star) ascends during the day. If (the degree of ascension of the star) falls between the point symmetrical (with the degree of the sun) and this degree, then (the star) ascends during the night. If the degree of descension is between the first two (points), then (the star) sets during the night. If (the degree of descension) is between the last two (points), then (the star) descends during the day." He (i.e. the author of the *Tuḥfa*) only refers to the degree of ascension of the star, and does not refer to the degree of the star, because (a star) may rise before or after its degree.

[١] فصل: في الأوقات.

[٢] لما اختلف سرعة[١] حركة الشمس وبطؤها، ثم باختلاف مطالع ما تقطعها الشمس [في[٢]] اليوم بليلته الحقيقي، وهو مدة عود الشمس[٣] بالحركة اليومية إلى نقطة فارقتها،[٤] أعني [ج ٦٠و] نقطة لها وضع [ب ٢٣٨و] معين بالنسبة إلى بقعة، [أ ٦٤ظ] كنقطة من دائرة نصف النهار أو الأفق، اختاروا لوضع الأوساط وقتا لا يختلف، وهو اليوم الوسطي، وهو مدة عودها إليه بسير الوسط، وهو زمان دور المعدل مع قطع قوس منه مساوية للوسط. وقد اختاروا تلك النقطة من دائرة نصف النهار، وهو أفق الاستواء، لكون التفاوت بين درج [خ ٦٦ظ] السواء والمطالع شيئا واحدا في جميع البقاع. ولم يعتبروا الطلوع والغروب[٥] في البلد.

[٣] ولما كان الاختلاف بين الحقيقي والوسطي بحسب الأمرين، فاعلم أن[٦] من وسط الدلو إلى وسط الثور، ومن وسط الأسد إلى وسط العقرب، [ف ٣١٨ظ] درج السواء أكثر من المطالع. وفي القوسين الآخرين أقل. والبعد الأوسط في أواخر الحوت. فإذا تحرك الشمس منها

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[١] سرعة: بسرعة [أ، ب]

[٢] في: الكلمة، سقطت في جميع النسخ، وأضيفت للمعنى

[٣] الشمس: الكلمة، سقطت، وأضيفت في الهامش [ب]

[٤] فارقتها: فارقها [ج]

[٥] الغروب: +«بحسب»، بعدها [ب]

[٦] أن: الكلمة، سقطت [أ، ب، خ]

[1] Chapter [16]: On Time.

[2] The speed and slowness of the sun vary; the ascensions (of the arcs) through which the sun moves during a true nychthemeron also vary, the latter being the period for the return of the sun during its daily rotation to the point of its departure, namely to a point which has a specific position with respect to some location, [f. 64v] such as a point on either the meridian or the horizon. (Having realized this,) they (i.e., the ancients) assumed a non-varying time (measure) for the determination of the mean motions, namely the mean (solar) day. This (mean day) is the period for the return (of the sun) to its (departure point) during mean motion, and this is the period for the rotation of the equator, plus the period for motion through an arc of it which is equal to the (arc of) mean motion. The above point was chosen to be the one on the meridian, which is the horizon (of a locality) at the equator, because the difference between the degrees of the ecliptic and the ascensions are the same at all localities. (On the other hand), they (i.e. the ancients) did not consider the ascensions and descensions for a specific locality.

[3] Now since the difference between the true and mean (days) is according to the above two (variations), then note that from the middle of Aquarius to the middle of Taurus, and from the middle of Leo to the middle of Scorpio, the degrees of the ecliptic are greater than the ascensions. In the other two arcs, (however), (the degrees of the ecliptic) are less. (Moreover), the mean distance (of the sun from the earth) is around the end of Pisces. Thus if the sun moves from that point

إلى وسط الثور، اجتمع نقصانان: نقصان المطالع والحركة. ثم إلى وسط الأسد المطالع زائدة، والحركة ناقصة [أ ٦٥و، ج ٦٠ظ] /فانجبر[1] نقصان المطالع، وبقي نقصان الحركة. [ب ٢٣٨ظ، هـ ٤٠ظ، خ ٦٧و] ثم إلى البعد الأوسط، أي[2] أواخر السنبلة، [ف ٣١٩و] اجتمع نقصانان. ثم زادت الحركة.[3] والمطالع ناقصة، والنقصان الذي[4] غالب على تلك الزيادة، إلى أن تساوتا[5] في أوائل العقرب. فهنا موضع كون اليوم الوسطي مساويا للحقيقي. ثم تغلب زيادة الحركة على نقصان المطالع إلى منتصف العقرب. فأن جاوزه، اجتمع الزيادات إلى وسط الدلو. /ثم تنقص المطالع والحركة زائدة، إلى أن[6] يتكافآ[7] في أواخر الدلو. فهنا صار الحقيقي والوسطي متساويين أيضا. ثم ينقص الحقيقي من الوسطي.

[٤] فظهر أن من أواخر الدلو إلى أوائل العقرب، الحقيقي ناقص من الوسطي، وفي القطعة الأخرى بالعكس. فأن جعل المبدأ أواخر الدلو، / فتعديل الأيام [أ ٦٥ظ] بلياليها يجب أن ينقص من تمام الدور. أما في

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[1] فانجبر: فانجر [ج]

[2] أي: إلى [ب]

[3] /فانجبر...الحركة: العبارة، شرح [أ]

[4] الذي: الكلمة، سقطت [ج]

[5] تساوتا: تساويتا [أ، ب]، ساواها [ج]

[6] أن: الكلمة، سقطت [أ]

[7] يتكافآ: فكانتا [أ]

to the middle of Taurus, then two decreases are compounded: the decrease of the ascension, and (the decrease) of the motion. Next, (from the middle of Taurus) to the middle of Leo the ascensions are additive, and the motion subtractive. [f. 65r] The decrease of the ascension is thus restored, while the decrease of the motion remains. Next, (from the middle of Leo) to the (other) mean distance, which is around the end of Virgo, two decreases are also compounded. The motion then increases, while the ascensions decrease. But the decrease continues to exceed the increase, until they become equal around the beginning of Scorpio. This is the point where the mean day is equal to the true day. Next, the increase of the motion exceeds the decrease of the ascensions till the middle of Scorpio. Thus if (the sun) passes beyond it (i.e. the middle of Scorpio), then the increases become additive till the middle of Aquarius. The ascensions then decrease while the motion is increasing, until they become equal at the end of Aquarius. At this point the true and mean (days) are also equal. Next the true (day) becomes less than the mean one.

[4] It is thus clear that, from around the end of Aquarius to the beginning of Scorpio, the true (day) is less than the mean, and conversely in the other section (of the ecliptic). Now if we start at around the end of Aquarius, then the equations of the days [f. 65v] with their nights (i.e., equation of time) should be subtracted from a complete revolution. As for

أواخر الدلو[1] إلى أوائل العقرب، فلأن الحقيقي ناقص من الوسطي، وقد [خ ٦٧ظ] وضعت الأوساط بحسب الوسطي، فلا بد من أن ينقص منه لتحصل الأوساط بحسب الأيام الحقيقية. وأما في القطعة الأخرى،[2] [ج ٦١و] /فلأنه اجتمعت في رأس العقرب نقصانات الأيام الماضية من أواخر الدلو إلى هنا،[3] وتلك الأيام ثمانية أشهر، والنقصانات المجتمعة ثمانية أزمان وثلاث أزمان،[4] فالوسط الموضوع في رأس العقرب يجب أن ينقص منه حصة تلك الأزمان، وهي دقيقة وثماني عشرة ثانية، ليحصل وسط أول الشهر[5] التاسع الحقيقي المتقدم[6] بثمانية أزمان وكسر على أول الشهر التاسع الوسطي. ثم بعد رأس العقرب، يقل ذلك النقصان شيئا فشيئا، فينقص في كل يوم أقل مما ينقص [ف ٣١٩ظ] في[ب ٢٣٩و] رأس العقرب، إلى إن تفنى تلك النقصانات عند تمام الدور، وهو أواخر الدلو. فيصير الحقيقي كالوسطي. وإن جعل المبدأ رأس العقرب، يكون بالعكس. لكن الحسّاب اختاروا الأول.

[٥] ثم إذا عرفت اليوم بليلته، فاعرف أجزاءه، وما يتركب منه.

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[1] /فتعديل...الدلو: العبارة، سقطت [ج]

[2] /ثم...الأخرى: العبارة، شرح [ج]

[3] هنا: ههنا [ج]

[4] /فلأنه...ثلاث أزمان: العبارة، شرح [أ]

[5] الشهر: شهر [ب]

[6] المتقدم: المقدم [ب]

(the section) from around the end of Aquarius to around the beginning of Scorpio, since the true (day) is less than the mean one, and since the mean motions are determined based on the (length of the) mean (day), therefore, the latter should be reduced in order to obtain the mean motions in true days. In the other section (of the ecliptic), the decreases of the days that passed from around the end of Aquarius to the beginning of Scorpio add up at this (beginning). The sum (of the above days) is eight months. The cumulative decreases are eight degrees of time and three degrees of time. Therefore, the mean motion at the beginning of Scorpio should be reduced by the share of these equatorial degrees, namely one minute and eighteen seconds, in order to determine the true middle of the first (day) of the ninth month, which is (in turn) ahead of the mean (middle) of the first (day) of the ninth month by eight and a fraction degrees of time. Next, after the beginning of Scorpio, the above reduction gradually diminishes, and what is subtracted from every day will be less than what was subtracted at the beginning of Scorpio, until these reductions vanish after the completion of one full revolution, which is around the end of Aquarius. The true and mean (days) thus become equal. If, (on the other hand), we start at the beginning of Scorpio, then the reverse holds. The calculators, however, opted for the first (starting point).

[5] Next, once the nychthemeron is known, you should know its parts, and that which is composed of it.

فالمشهور أن قوس النهار نصف الدور، أو هذا مع ضعف[١] تعديل النهار أو نقصانه. لكن في الحقيقة النهار من زمان طلوع نصف جرم الشمس إلى زمان غروب نصف جرمها. وهذا زائد على الأول بمطالع ما تسير الشمس بحركتها الخاصة في ذلك الوقت. [أ ٦٦و، هـ ٤١و] فأذا قسم الدور، وهو /شس درجة، على كد ساعة، [خ ٦٨و] خرج يه زمانا.[٢] ثم قسم كل زمان على أربعة، حتى يكون واحد من ستين من ساعة، وهي دقيقة، ساعة كل منها يه دقيقة من أجزاء الدرج.[٣] [ج ٦١ظ] لكن في الحقيقة الساعة أكثر من يه زمانا، لأن الشمس قد تحركت. فأذا أخذت حصة حركتها الوسطية، تكون دقيقتين[٤] ونصف تقريبا. فالساعة يه زمانا مع [ف ٣٢٠و] هذا الكسر. وأما حصة حركتها التقويمية، فلا ضبط لها. وهذه الأقسام ساعات مستوية.[٥] فأن قسم كل من القوسين على إثني عشر، فكل قسم ساعة معوجة، كل منها نصف سدس النهار أو الليل. لكن أجزاءها مختلفة، وعددها متساو،[٦] والمستوية على العكس.

[٦] [ب ٢٣٩ظ] والسنة إما شمسية، وهي شسه يوما وربع يوم

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[١] ضعف: الكلمة، سقطت [أ، ب]

[٢] زمانا: +«من»، بعدها، البروج [ج]

[٣] /شس...الدرج: العبارة، شرح [أ]؛ الدرج: البروج [ج]

[٤] دقيقتين: دقيقتان [أ، ب]

[٥] مستوية: سيتوية [أ، ب]

[٦] متساو: مساو [أ، ب]

The most commonly accepted is that the arc of daylight is either half a revolution, or that plus or minus double the equation of daylight. In reality, however, the day is from the time of rising of half the body of the sun to the time of setting of that half. The latter, however, is greater than the former by the ascensions (of the arc of the ecliptic) through which the sun moves, during the above time, as a result of its own (yearly) motion. [f. 66r] If a (complete) revolution, that is 360 degrees, is divided by 24 hours, then 15 (degrees of) time are obtained. Next, each degree of time is divided by four, so that (the result) is one sixtieth of an hour, that is a minute whose hour is equal to 15 degrees of the said degrees. In reality, however, an hour is more than 15 degrees of time, because the sun moves (during this hour). Thus, if the anomaly of its mean motion (i.e. that of the sun) is calculated, it will be approximately two minutes and a half. An hour is then 15 degrees of time plus this fraction. As for the anomaly of its true motion, there is no control over it. The above parts are equal hours. If, however, each of the two arcs (i.e. the arc of daylight and the arc of night) is divided by twelve, then each part is an unequal hour, each of which is one half of one sixth of either the day or the night. The degrees of (the hours of either one of the two arcs) are thus different, and their numbers are equal, and conversely for the equal hours.

[6] The year may be a solar one, and this is 365 days plus a quarter (of a day)

إلا[1] كسر. وشهورها قد توجد بحسب نقل الشمس إلى البروج. فمن الشمالية الجوزاء لب يوما، وكل من الباقي لا. ومن الجنوبية القوس والجدي كط، وكل من الباقي ل. فأن الشمس إذا قطعت ربع الخارج من نقطة الأوج، فالاختلاف ب يب، تقطعها الشمس في يومين وقريب ربع. فهذا[2] هو التفاوت بين قطع ربع الخارج وربع الممثل. وهكذا في النطاق الرابع. فالمجموع أربعة أيام وقريب [خ ٦٨ظ] نصف، وهو التفاوت بين قطع نصف الخارج وقطع نصف الممثل. فالتفاوت[3] بين قطع القسمين من الممثل، أي الأوجي والحضيضي، ضعف هذا، وهو تسعة أيام تقريبا.

[٧] وقد يؤخذ الشهر ثلاثين ثلاثين،[4] [أ ٦٦ظ] فيبقى خمسة أيام تسمى مسترقة. ثم يزاد في كل أربع سنين يوم[5] يسمى كبيسة.

[٨] وقد تؤخذ السنة شسه يوما، كاليزدجردية. وشهورها ثلاثون ثلاثون وخمسة مسترقة، بلا كبيسة فيها. [ف ٣٢٠ظ] وإما قمرية، وهي شند يوما وخمس وسدس من يوم. فيؤخذ كل سنة شند يوما، ثم في

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[1] إلا: و [أ، ب]

[2] فهذا: وهذا [ج]

[3] فالتفاوت: بالتفاوت [ب]

[4] ثلاثين: الكلمة، سقطت [ج]

[5] يوم: يوما [ج]، يوم، وصححت إلى يوما [ب]

less a fraction. Its months may be determined by the displacement of the sun through the zodiacal signs. Among the northern (signs, the motion of the sun in) Gemini takes 32 days, and 31 (days) in each of the remaining ones. In the southerly (signs), each of Sagittarius and Capricorn is 29 (days), while the remaining ones are 30 (days). For if the sun moves through a quadrant of the eccentric, starting from the apogee point, then the difference is 2;15 (degrees), and the sun moves through it in approximately two days and a quarter (of a day). This is the difference between the time taken (by the sun) to move through one quadrant of the eccentric and one quadrant of the parecliptic. The same is true in the fourth sector. The sum is approximately four days and one half (of a day), which is the difference between the motion through one half of the eccentric and one half of the parecliptic. The difference between the motion through the two parts of the parecliptic, that is the apogee and perigee portions, (and motion through the two parts of the eccentric) is thus twice the above, and this is approximately nine days.

[7] The months may be taken to be thirty (days) each, [f. 66v] leaving five days which are called epagomenal (days). Moreover, every four years one day is added, and this is called a leap (day).

[8] The year, (on the other hand) may be assumed to have 365 days, such as the *Yezdegird* (year). Its months are thirty (days) each, plus five epagomenal (days), and it has no leap (days). (A year) can also be a lunar one, and this is 354 days and a fifth and a sixth of a day. Each year thus has 354 days, and

كل ثلاث[١] سنين يزاد[٢] يوم هو كبيسة. ثم في ثلاثين سنة[٣] يزاد يوم آخر، حتى يكون في ثلاثين [ج ٦٢و] سنة أحد عشر يوما كبيسة. وشهورها برؤية الهلال. وقد تؤخذ بحسب الأمر الأوسط، شهر ل وشهر كط.

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[١] ثلاث: ثلاثين، ثم صححت [ب]

[٢] يزاد: يزداد، ثم شطبت الدال [ب]

[٣] سنة: يوما [أ، ب]

every three years a leap day is added. Moreover, every thirty years another day is added, so that, (as a result), in thirty years there is eleven leap days. Its months are determined by sighting the new moon. They can also be determined on the average to be one month of 30 (days), and the next of 29 (days).

[١] فصل: في الصبح والشفق.

[٢] الهواء البسيط الصافي[١] لا يقبل الضوء، بل الكثيف، وهو كرة البخار. وأجزاؤها[٢] المضيئة من الشمس، إذا قربت من الناظر في آخر الليل شرقا،[٣] يميل[٤] مخروط الظل إلى المغرب، فيبدو[٥] الصبح. وأول ما يبدو[٦] هو[٧] الكاذب، وهو بعيد من الأفق، وما يقرب منه مظلم.

[٣] لأنا نفرض سطحا قائما على الأفق، ينصف[٨] الشمس والأرض والمخروط، بحيث يجعل أحد النصفين شماليا والآخر جنوبيا. فيحدث مثلث أ ب جـ. فرأس المخروط أ، وقاعدته، وهي قطر الأرض، ب جـ، وأحد الضلعين، وهو خط الشعاع [هـ ٤١ظ] المماس لأعلى المخروط، أب، والآخر[٩] المماس لأسفله، أ جـ. فخط أ ب وسط الأجزاء المضيئة عرضا. ثم إذا قام عليه عمود خارج من البصر، فموضعه أقرب إلى

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[١] الصافي: الصافية [أ، ب]

[٢] أجزاؤها: أحماءها [ج]

[٣] شرقا: الكلمة، سقطت [ج]

[٤] يميل: بالميل [ج]

[٥] فيبدو: فيبدأ [ج]

[٦] يبدو: يبدأ [ج]

[٧] هو: وهو [ب، ج]

[٨] ينصف: لنصف [ج]

[٩] والآخر: ولا آخر [ب]

[1] Chapter [17]: On Dawn and Twilight.

[2] Simple and clear air does not accept light, rather the dense (air), which is the sphere of vapor (atmosphere), does. If, at the end of the night, the parts of the latter which are illuminated by the sun approach the observer from the east, then the shadow cone inclines to the west. Dawn becomes visible. The first to appear is the false (dawn), and it is far from the horizon, whereas (the parts) close to it (i.e. to the horizon) are dark.

[3] Consider a plane which is perpendicular to the horizon, and which bisects the sun and the earth and the shadow (cone), such that one of the two halves is northerly while the second is southerly. Triangle *ABG* [fig. 93 in the commentary] is obtained. The head of the cone is *A*, and its base, namely the diameter of the earth, is *BG*. One of the two sides, namely the ray line which is tangent to the upper part of the cone, is *AB*, while the other (side), which is tangent to its lower (part), is *AG*. Line *AB* is thus the middle line of the parts which are illuminated in width. If then a perpendicular is issued from the observer (to line *AB*), then the location (of their intersection) is closer to

الناظر من سائر أجزاء خط أب. فهو يبدو أولا، لا ما يقرب من الأفق.[١] [ب ٢٤٠و] لأن من كرة البخار، ما يبعد عن الأفق ألطف مما يقرب منه. فإذا كان الضوء ضعيفا،[٢] [خ ٦٩و] يؤثر في الألطف لا في الأكثف. على أن الهواء الكثيف المظلم حاجب هنا.

[٤] [ف ٣٢١و] وزعم كثير من الناس أن الكاذب يعقبه ظلام. فإن صح ذلك، فسببه أن في آخر الليل ترتفع الأبخرة [أ ٦٧و] في جانب المشرق، وليس الضوء بحيث يؤثر فيها. فيختفي الكاذب ولم يطلع الصادق بعد. وذا في زمان لطيف، حتى إذا قوي الضوء طلع الصادق. فالأول كاذب مستطيل، ثم صادق مستطرد[٣] متدرج من البياض إلى الحمرة. والشفق بالعكس.

[٥] وزمان كل منهما في الاستواء،[٤] [ج ٦٢ظ] والشمس في الاعتدال، ساعة وخمس.[٥] لأن المعدل هو دائرة الارتفاع، /ومبدأ ظهور الصبح[٦] إذا كان بين الشمس والأفق من دائرة الارتفاع ثماني عشرة درجة. وثماني عشرة درجة من المعدل تطلع في ساعة وخمس ساعة.[٧]

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[١] من الأفق: الأفق [ج]

[٢] ضعيفا: حقيقيا [ج]

[٣] مستطرد: مستطر [أ، ب]

[٤] الاستواء: الكلمة، غير واضحة [ج]

[٥] خمس: +«ساعة» [ج]

[٦] الصبح: الشمس [ب، هـ، خ]

[٧] /ومبدأ...خمس ساعة: العبارة، شرح [ب، خ]

the observer than the rest of the points of line *AB*. It (the above intersection) is thus the first to appear, in contrast to what is close to the horizon. For (those parts) of the sphere of vapor which are farthest from the horizon are less dense than the parts which are close to it. So if the light is weak, then it affects the less rather than the more dense. The dense and dark air thus conceals in this case.

[4] Many people have claimed that the false (dawn) is followed by darkness. If this were true, then the reason would be that towards the end of the night vapors rise [f. 67r] on the eastern side (of the horizon), while light is such that it could not yet affect them (the vapors). The false (dawn) thus disappears before the true dawn rises. This lasts for a little time, and as soon as the light becomes stronger, the true (dawn) rises. Therefore, the first would be an extending false (dawn), followed by a true one which gradually changes from white to redness. Twilight is opposite (the dawn).

[5] At the equator, and when the sun is at the equinoctial point, the duration of either (dawn or twilight) is one hour and a fifth. (This is true) because the equator is the altitude circle, and the beginning of the visibility of the dawn is when the distance between the sun and the horizon along the altitude circle is eighteen degrees. (Moreover), eighteen degrees of the equator rise in one hour and a fifth.

وفي غير الاعتدال، أكثر. [أ ٦٧ظ، ب ٢٤٠ظ، ج ٦٣و، ف ٣٢١ظ، هـ ٤٢و، خ ٦٩ظ] وكل جزئين يتساوى بعدهما عن نقطة الاعتدال، فزمانا كل منهما فيهما متساويان.

[٦] وهذا من خواص خط الاستواء. [ف ٣٢٢و، خ ٧٠و] /وأما في الآفاق المائلة، ففي الإقليم الرابع، كل منهما ساعتان والشمس في المنقلب الصيفي، وساعة وثلث والشمس في مقابلته. فأن هنا القوس من مدار الشمس تحت الأرض أقرب من الانتصاب،[١] فطلوعها يكون أسرع.[٢]

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[١] الانتصاب: الانتصاف [أ، ب]

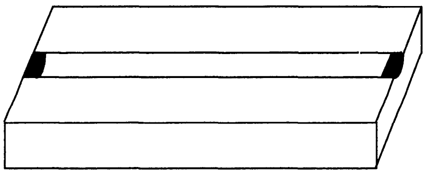
[٢] /وأما...أسرع: العبارة، شرح [خ]

(If the sun) does not fall on the equinoctial point, then (the degrees) are more. [f. 67v] (Furthermore), if any two points (on the ecliptic) are equidistant from the equinoctial point, then the duration of either (dawn or twilight) at these two (points) will be equal.

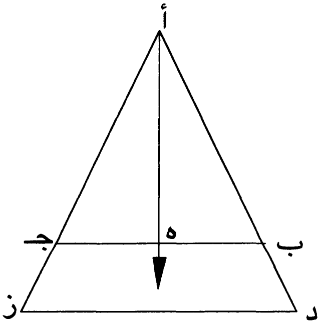
[6] The above are the characteristics of the terrestrial equator. As for the inclined horizons, (such as a locality) in the fourth climate, (the duration of) each of them (i.e. dawn and twilight) while the sun is at the summer solstice is two hours, whereas it is one hour and a third when the sun is at the opposite (point). (This is true) because, in the latter (position), the arc of the day circle of the sun which is below the (horizon) of the earth is close to being vertical. Its rising is thus faster.

[١] فصل: في استخراج خط نصف النهار وسمت القبلة.

[٢] يتخذ آلة تسوية الأرض. وهي إما خشب طولاني ذو أربعة سطوح متوازية، ينقر على وجهه أنبوبة[١] ويسد طرفاها هكذا (شكل ٩٤[٢]). وإما مثلث من خشب بهذه الصورة (شكل ٩٥[٣])، على أن خط أ ب مساو لخط أ جـ، [ب ٢٤١و] وخط أد مساو لخط أز. وينصف ب جـ على نقطة ه، ويعلق من أ شاقول، بحيث يكون بين خط ب جـ وخط دز.



شكل ٩٤



شكل ٩٥

[٣] فإذا أريد تسوية الأرض، توضع الآلة على الأرض، وتملأ الأنبوبة ماء. فإن لم [أ ٦٨و] يمل الماء إلى أحد الجانبين، فالأرض مستوية. وإن

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[١] أنبوبة: الكلمة، غير واضحة [أ]

[٢] شكل ٩٤: الشكل، سقط [ج]

[٣] شكل ٩٥: الشكل، سقط [ج]

[1] Chapter [18]: On the Determination of the Line of Midday (i.e. Local Meridian), and the Azimuth of the *Qibla*.

[2] (We first) take an instrument for leveling the ground. This can be a longitudinal (piece) of wood having four parallel surfaces, such that we carve a tube on its surface, and then plug its (i.e. the tube's) two ends in this manner (figure 94). (The instrument) can also be a wooden triangle having this shape (figure 95), such that line *AB* is equal to line *AG*, and line *AD* is equal to line *AZ*. *BG* is then bisected at point *E*, and a plumb line is suspended from *A*, such that it falls between lines *BG* and *DZ*.

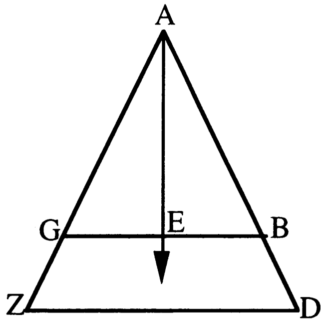

FIGURE 95

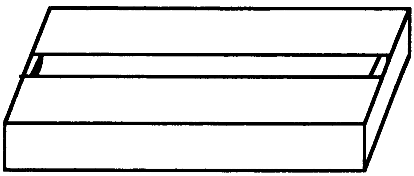

FIGURE 94

[3] In order to level the ground, the (first) instrument is placed on it, and the tube filled with water. Now, if [f. 68r] the water does not tilt in either one of the two directions, then the ground is level. When

سويتها بالمثلث، فخيط الشاقول، إن لم يمل على نقطة ه، فالأرض مستوية. فالأحسن أن يوضع لوح مستوي الوجه، ثم يسوى بما ذكر.

[٤] [ج ٦٣ظ] /ثم يحكم اللوح على الأرض بالجص. ثم تدار دائرة ويثقب[١] مركزها. ويغرز في الثقبة مسلة[٢] أو مغزل. ويعرف أنه قائم بأن يكون بعد رأسه[٣] عن ثلاث نقط [هـ ٤٢ظ] من المحيط [ف ٣٢٢ظ] متساويا.

[٥] ثم يؤخذ بالأصطرلاب[٤] ارتفاع الشمس، وهي شرقية، سواء كان الظل متجاوزا عن محيط الدائرة، أو يكون رأس الظل على المحيط. /ويعلم علامة الظل على المحيط.[٥] ثم يؤخذ مثل ذلك الارتفاع إذا كانت الشمس غربية،[٦] [خ ٧٠ظ] ويعلم علامة أخرى. وتنصف القوس التي بين العلامتين، فالقطر المخرج من المنتصف إلى الطرف الآخر خط نصف النهار. وإذا نصف كل من النصفين، وأخرج آخر /من منتصف[٧] أحد النصفين إلى منتصف النصف الآخر، فهو خط المشرق والمغرب. وهو في سطح دائرة أول السموت.

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[١] ويثقب: أو يثقب [أ، ب، ج، هـ]

[٢] مسلة: سلة [هـ]

[٣] بعد رأسه: بقدر شئ [هـ]

[٤] بالاصطرلاب: باقي الاصطرلاب [ج]

[٥] /ويعلم...المحيط: العبارة، سقطت [ج]

[٦] /ثم...غربية: العبارة، شرح [ج، هـ]

[٧] من منتصف: بين المنتصف، ثم صححت فوق السطر [أ]

using the triangle for leveling, if the plumb line does not incline away from point *E*, then the ground is level. (Furthermore), it is better to place a board which has a plane surface, and then level (the board) as mentioned above.

[4] The board is secured to the ground with gypsum. Next, a circle is drawn (on it), and its center pierced. A needle or a spindle is then inserted in the hole. The latter will be perpendicular if its head is equidistant from three points on the circumference.

[5] We then measure by means of an astrolabe the altitude of the sun, while it is easterly, such that either the shadow (cast by the spindle extends) beyond the circumference of the circle, or the head of the shadow falls on the circumference. The (crossing point of the) shadow is marked on the circumference. Next, we measure a similar altitude, while the sun is westerly, and make another mark. We then bisect the arc which falls between the two marks, and the diameter issued from this midpoint to the other side (of the circle) is the meridian line. If, (on the other hand), each of the two (resulting) halves was bisected, and if another (line) was issued from the middle of one of the two halves to the middle of the other, then (this line) is the east-west line. (The latter line) falls in the (plane of the) prime vertical.

[٦] وإن شئت فارصد زمان دخول الظل في الدائرة وخروجه عنها، ويعلم موضع دخوله وخروجه، وينصف ما بينهما.[١] [أ ٦٨ظ، ب ٢٤١ظ] واختير لهذا الطريق، وهو طريق رصد دخول الظل في الدائرة وخروجه عنها، أن يكون المقياس مقدار ربع القطر. [ج ٦٤و] فيكون [ف ٣٢٣و] الظل زمان الدخول والخروج ضعف المقياس. إذ[٢] في أول النهار وآخره إن كان الظل سريع الحركة، إلا أن رأسه متشتت، عسر الإدراك. وعند قريب نصف [خ ٧١و] النهار بطيء الحركة. فسرعة التحرك[٣] مع عدم التشتت في حدود ما ذكرنا من المقدار.

[٧] وهذا العمل [أ ٦٩و، هـ ٤٣و] عند كون الشمس في المنقلب، أولى من أن يكون في الاعتدال، لئلا يظهر بحركة الشمس الخاصة فيما بين الارتفاعين تفاوت في الميل[٤] بحيث يحس. فإنه إذا كان الشمس في الاعتدال، يتفاوت الميل في كل يوم بليلته كد دقيقة، من[٥] الزمان الذي يكون بين الارتفاع الشرقي والغربي تفاوت الميل بهذا الحساب. وإذا كانت في الانقلاب، [ب ٢٤٢و] لا يظهر التفاوت في ثلاثة أيام بمقدار [ف ٣٢٣ظ] دقيقة. والارتفاع إنما[٦] يتفاوت بالميل. فإنه إذا

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[١] /من منتصف...بينهما: العبارة، شرح [ب]

[٢] إذ: لا [ج]

[٣] التحرك: الحركة [ب، ج]

[٤] الميل: الكلمة، سقطت [ب]

[٥] من: ففي [ج]

[٦] إنما: بهما [أ]، لهما [ج]

[6] Alternatively, one can observe the time when the shadow enters into the circle and exits from it, mark the location of its entrance and exit, and bisect (the arc) that falls between them. [f. 68v] (Moreover), the measure (of the spindle) which is chosen for this method, namely the method of observing the entrance of the shadow into the circle and its exit from it, is equal to one quarter of the diameter. The shadow at the time of entrance and exit is thus equal to twice this measure. (The above choice is made) because the movement of the shadow at both the beginning and the end of the day is fast, and its head is dispersed and hard to discern. (Moreover), at around midday, its motion (i.e. that of the shadow) is slow. (On the other hand), the motion is fast, and it (i.e. the shadow) is not dispersed at around the above mentioned measure.

[7] The above procedure [f. 69r] is preferable when the sun is at the solstice, rather than at the equinoctial point, so that no detectable variation in declination may occur due to the proper motion of the sun while it is moving between the two (equal) altitudes. For when the sun is at the equinoctial point, the declination varies during every nychthemeron by 24 minutes of time degrees by which the variation in the declination between the easterly and westerly altitudes is calculated. If, (on the other hand), the sun is at the solstice, then the variation does not exceed one minute in three days. (Moreover), the altitude (at midday) only varies with the declination. For if

زيد الميل على ارتفاع معدل [ج ٦٤ظ] النهار، أو نقص الميل عنه، يحصل ارتفاع نصف النهار. وغرضنا استخراج خط نصف النهار، وهو منتصف زمان طلوعه و غروبه [خ ٧١ظ] بالحركة اليومية. وذلك يعرف بارتفاع الشمس. فإذا كان تفاوت الارتفاع لمجرد الحركة اليومية، يصح العمل. لكن إذا كان التفاوت باعتبار أمر آخر، وهو حركته الخاصة، فيكون في العمل قليل خلل.

[٨] /ثم الصيفي أولى من الشتوي: فأن مدار الشمس أقرب من[1] الانتصاب. فنقصان الارتفاع وازدياده بالحركة اليومية أسرع. وأيضا الهواء أصفى. وإحساس رأس الظل يكون أيسر.

[٩] وأيضا إن جعل المقياس ربع القطر كما ذكر، فزمان كون الظل ضعفه يكون قريبا من زمان نصف النهار، فيكون الظل بطيء الحركة. وإن جعل المقياس أقل من الربع، حتى يكون الظل أكثر من ضعف المقياس عند الدخول في الدائرة والخروج منها، كان رأس الظل متشتتا. فهذا العمل في المنقلب الصيفي أولى.[2]

[١٠] وأما سمت القبلة، فأن كان التفاوت بين مكة والبلد في العرض فقط، فالسمت على خط نصف النهار. أو في الطول فقط، قيل:[3] فعلى خط المشرق والمغرب. لكن رد هذا بأن الطول إذا كان متفاوتا، لم يكن خط المشرق والمغرب متحدا. فأن كان طول مكة أقل من طول البلد،

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[1] من: إلى [ج]

[2] /ثم...أولى: العبارة، شرح [ب]

[3] قيل: ميل [ج]

the declination is added to, or subtracted from the altitude of the equator, then the midday altitude will be obtained. (Furthermore), our purpose is to extract the meridian line, which is the middle of the time of rising and setting due to the daily motion, and that is found from the altitude of the sun. Thus, had the variation of the altitude been a result of merely the daily motion, then the procedure would have been correct. If, however, the variation was due to the consideration of some other factor, namely its (i.e. the sun's) proper motion, then there would be some error in the procedure.

[8] On the other hand, the summer (solstice) is preferable to the winter one. For the day circle of the sun (at the summer solstice) is almost vertical. The decrease and increase of the altitude due to the daily motion is thus faster. Moreover, the air is clearer, and the detection of the shadow is easier.

[9] Furthermore, if the measure (of the spindle) is taken equal to one quarter of the diameter (of the circle), as mentioned above, then the time at which the shadow equals double (the measure) is around the time of midday, and the shadow will be slow. If, (on the other hand), the measure is taken less than one quarter, such that the shadow is greater than double the measure as it enters into and exits from the circle, then the head of the shadow will be dispersed. Therefore, the above procedure is preferable at the summer solstice.

[10] As for the *qibla* azimuth, if the difference between Mecca and the locality is only in latitude, then the azimuth is along the meridian line. (In the case when the difference is) only in longitude, it is maintained (by some) that (the azimuth) is along the east-west line. This, however, is refuted because, if the longitudes are different, then the east-west lines will not be united. Thus if the longitude of Mecca is less than the longitude of the locality,

فهي على يمين نقطة مغرب[1] البلد. وإن كان أكثر، فعلى يسار نقطة مشرقه، فأنه أذا كان العرض متساويا،[2] وطول مكة أقل، فالخط [أ ٦٩ظ] المار على رأس البلد ورأس مكة مواز لخط الاستواء. وخط المشرق ينتهي إلى خط الاستواء. فمكة على يمين ذلك الخط. [ف ٣٢٤و] وقس على ذلك ما إذا كان طولها أكثر.

[١١] [ب ٢٤٢ظ، خ ٧٢و] وإن كان التفاوت فيهما، /فالعمل بالدائرة الهندية أن يؤخذ طول [ج ٦٥و] مكة شرفها الله، وهو عن الساحل سز ي، وطول بخارا فو نه؛[3] فالتفاوت ك تقريبا. ونعده من نقطة الشمال، ونعلم علامة. /وكذا من نقطة الجنوب [هـ ٤٣ظ] إلى جانب المغرب، ونعلم علامة أخرى.[4] ونصل بينهما خطا موازيا لخط نصف النهار. ويؤخذ عرض مكة، وهو[5] كا م، وعرض بخارا لط نه. فالتفاوت يح وكسر. فنعده[6] من نقطة المشرق، وكذا من نقطة المغرب، إلى جانب الجنوب. فنصل بينهما خطا موازيا لخط المشرق والمغرب. فيلتقي الخطان، فنخرج من مركز الدائرة إلى الملتقى خطا، فهو سمت القبلة.

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[1] مغرب: المغرب، ثم شطبت أل التعريف [ج]

[2] متساويا: مساويا [ج]

[3] /فالعمل...فونه: العبارة، شرح [ج]؛ فونه: قونه [أ، ب]

[4] /وكذا...أخرى: العبارة، شرح [ج]

[5] وهو: الكلمة، سقطت [ج]

[6] فنعده: فبعده [ج]

then the former falls to the right of the west point of the locality. If (on the other hand, the longitude of Mecca is) more (than that of the locality), then (the former falls) to the left of the east point (of the locality). (This is true) because, when the latitudes are equal, and when the longitude of Mecca is less (than that of the locality), then the line [f. 69v] which passes through the zenith of the locality and the zenith of Mecca will be parallel to the terrestrial equator. (Moreover), the east line ends at the terrestrial equator. Therefore, Mecca will be to the right of that line. A similar (argument) also applies when the longitude (of Mecca) is greater (than that of the locality).

[11] Now (in the case) when the difference is in both (latitude and longitude), the method (for finding the azimuth of Mecca) by means of the Indian circle is (as in the following example): consider the longitude of Mecca, may it be honored by God, which is 67;10 (degrees) when measured away from the cost (of the encompassing sea), and the longitude of Bukhārā which is 86;55 (degrees); the difference is approximately 20 (degrees). We count (this difference) from the north point towards the west, and make a mark. Similarly (we count this difference) from the south point towards the west, and make another mark. We then connect the two (marks) by a straight line parallel to the meridian line. (Next), we consider the latitude of Mecca, which is 21;40, and the latitude of Bukhārā, which is 39;55; the difference is 18 (degrees) and a fraction. We count (this difference) from the east point, and similarly from the west point, towards the south. We then connect the two (marks) by a straight line parallel to the east-west line. The two lines thus intersect. We issue a line from the center of the circle to the intersection (point), and this will be the azimuth of the qibla.

[١٢] ولما كان تفاوت الطول والعرض قريبا من المساوي، كان القبلة بين المغرب والجنوب، لا على ما[١] في الوسط، بل مائل[٢] إلى المغرب بشيء قليل. وقد وجدته ثلاث درجات. فالبعد بين مغرب الربيع وسمت القبلة مب درجة، و بين مغرب الشتاء وسمت القبلة مح[٣] درجة. [أ ٧٠و، خ ٧٢ظ، ف ٣٢٤ظ]

[١٣] وبالاصطرلاب، أن الشمس في الجزء الذي يمر على سمت مكة، وهو كجـ[٤] من الجوزاء أو ز[٥] من السرطان، فأن ميل كل واحد من [ج ٦٥ظ] الجزئين [ب ٢٤٣و] كا م، مساو لعرض مكة. فالشمس، إذا كانت في إحدى هذين الجزئين، تمر على سمت رأس مكة. يوضع ذلك الجزء على خط وسط السماء، ويعلم موقع مري رأس الجدي[٦] من أجزاء الحجرة. ثم يعد من موضع العلامة إلى جانب اليسار تفاوت ما بين الطولين، وهو ك في بخارا. ويعلم عليه علامة. ثم يوضع[٧] مري رأس الجدي على هذه العلامة، فينظر أن جزء الشمس على أي موضع[٨] وقع

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[١] ما في: حاق [أ]، غير واضحة [ب]

[٢] مائل: ما يلي [ج]

[٣] مح: يح [ج]

[٤] كجـ: كح [ب]

[٥] ز: الكلمة، سقطت [ب]، ومكانها فراغ [أ]، مجـ [ج]

[٦] الجدي: السرطان [ج]

[٧] يوضع: نضع [ج]

[٨] موضع: جزء [ب]

[12] Since the differences in longitude and latitude (in the above example) are almost equal, the (direction) of the qibla will be slightly inclined to the west between the west and the south, and will not be exactly in the middle. I have found that (inclination) to be three degrees. The (angular) distance between the setting point of spring and the azimuth of the qibla is thus be 42 degrees, whereas it is 48 degrees between the setting point of the winter and the azimuth of the qibla.

[13] [f. 70r] (The method of finding the azimuth of Mecca) by means of the astrolabe (is as follows): let the sun fall on the point which passes through the azimuth of Mecca, namely on 23 (degrees) of Gemini, or 7 (degrees) of Cancer. Since the declination of each of these two points is 21;40 (degrees), which is equal to the latitude of Mecca, therefore, if the sun passes through either one of them, then it will pass through the zenith of Mecca. We then place that point on the meridian line, and mark the location of the pointer to the beginning of Capricorn on the rete. Next, we count the difference in longitudes to the left side of the position of the mark, which is 20 (degrees) in Bukhārā. We make a mark at it. We then place the pointer at the beginning of Capricorn on this (latter) mark, and we check the

من مقنطرات الارتفاع الغربي. فيرصد ذلك الارتفاع. فإذا كان الارتفاع الغربي ذلك المقدار، تنصب خشبة أو يعلق شاقول. فظل الخشبة أو خيط الشاقول هو سمت القبلة. والله أعلم.[١]

[١٤] /تم تصنيفه ظهرة يوم الأربعاء، السادس [ف ٣٢٥و] من ربيع الآخر، سنة سبع وأربعين وسبعمائة، في مقام شرعأباد من مدينة بخارا، صانها الله تعالى، مع سائر بلاد المسلمين، عن الآفات والمخافات.[٢]

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[١] والله أعلم: العبارة، سقطت [أ، ج]

[٢] /تم...المخافات: العبارة، سقطت وكتب مكانها تعريف بالناسخ [ج]؛ أيضا تحتها تعريف بالنسّاخ [أ، ب، هـ، خ]؛ تحتها «صدر الشريعة، الإمام العلامة والهمام الفهامة، عبيد الله بن مسعود، رحمه الله تعالى ونفعنا بعلومه، مات سنة سبعة وأربعين وسبعمائة»[ب]

westerly almucantars of latitude on which the degree of the sun falls. This altitude (of the sun) is then observed. When its westerly altitude becomes equal to the above (measured) value, we set up a piece of wood or a plumb line. The shadow of the wood or of the plumb line is (along) the azimuth of the qibla. And God Knows best.

[14] The composition (of this book) was completed on the noon of Wednesday, the sixth of Rabīʻ al Ākhir, of the year seven hundred and forty seven, at the quarter of Sharʻābād in the city of Bukhārā, may God preserve it, together with all the lands of the Muslims, from harm and danger.

COMMENTARY

CHAPTER 1

[2] The first quotation on lines 2 and 3 Of this paragraph is from the Qur'ān, (50, 6). The one on line 4 is from Qur'ān, (33, 46). The last sentence of the paragraph is a rephrasing of Qur'ān, (67, 5).

[4] The Arabic title of the book is *Ta'dīl Hay'at al-Aflāk*. The word *ta'dīl* means modification or adjustment in the sense of straightening out. The purpose of this work is thus to produce a revised and corrected astronomy, after solving the problems encountered in previous works on the subject.

The Arabic word used for enlightening is *tabṣira*, probably alluding to a work by Bahā' al-Dīn al-Kharaqī (d. A.H. 533, A.D. 1138/9), called *al-Tabṣira fī 'Ilm al-Falak* (see Suter 276, p.116). The Arabic word for reminding is *tadhkira*, this time alluding to the celebrated work of Naṣīr al-Dīn al-Ṭūsī (d. A.H. 672, A.D. 1274), called *al-Tadhkira fī 'Ilm al-Hay'a*, which was compiled on A.H. 659 (= A.D. 1260/61) (see Saliba, "First Ptolemaic Astronomy," 1979, p. 575).

[5] The definition of the science of astronomy put forth in this section clearly separates its subject matter from the subject matter of Aristotle's *On the Heavens*. Although Aristotle's work addresses mainly the question of the nature of motion, he perceived it as one which also deals with the configurations, quantities, and directions of such motions (see for example, Aristotle, *On the Heavens*, Book I, chapter 3; Book II, 2, 9, 12). A similar work by Ibn Sīnā (d. A.H. 528, A.D. 1037) is clearer on making a distinction between essence and configuration. Ibn Sīnā's famous al-Shifā' includes a section "On the Heavens and the World", in which he clearly ascribes the science dealing with occurrences of specific configurations, motions, or quantities to a mathematical discipline rather than a physical one (see for example, *Shifā'*, part 2, pp. 37, 47, 48).

More subtle, however, is the divergence of Ṣadr's definition from those of *Tadhkira* (mentioned above) and *al-Tuḥfa al-Shahiyya* of Quṭb al-Dīn al-Shīrāzī (d. A.H. 710, A.D. 1311). In the *Tadhkira*, astronomy is only defined by its subject matter, without an independent statement as to its nature as a science. According to Ṭūsī, "the subject of astronomy is the upper and lower simple bodies with respect to their quantities, qualities, positions, and intrinsic motions" (see *Tadhkira* , p. 90). The difference between these two definitions is not a simple question of arrangement of terms, but a basic one; Ṭūsī's reference to "simple bodies" automatically excludes compound bodies which Ṣadr wants to include, such as the different layers of fire, air, and earth. Moreover, had Ṭūsī not restricted his definition to "simple bod-

ies" he would have included the meteorological phenomena, which, according to Ṣadr, is the subject of a different science. More generally, Ṭūsī uses "qualities" (*kayfiyya*) instead of "configuration" (*hay'a*), and although the latter is subsumed within the former, the word "qualities" would extend the scope of concern of the science of astronomy to include questions that belong to the fields of physics or even metaphysics (see MS *A*, f. 1v, 2r).

In the *Tuḥfa*, Shīrāzī defines astronomy as a "science (*'ilm*) through which one would know (*yu'rafu fīhi*) the numbers of the upper bodies and their configurations, their positions and the causes of their variations, the quantities and directions of their motions, and the measures of distances and bodies..." (see *Tuḥfa*, f. 0v, 1r). In the commentary to his work, Ṣadr objects to this definition on the grounds that the word *'Ilm* implies a knowledge of general principles from which the knowledge of particulars follows; the above definition, however, does not specify these general principles. Moreover, Ṣadr posits that the science of astronomy is, in contrast to medicine, nothing but the direct knowledge of the particulars, and not the knowledge of some general principles from which such particulars are deduced (see *A*, f. 2r).

The subject matter of astronomy is, according to Ṣadr, defined as those bodies under the constraints of specific configurations, in contrast to defining astronomy as the study of bodies together with their configurations. The difference is that the configurations are contingent on the bodies and are not the subject of inquiry by themselves.

While in the *Tuḥfa* the principles of astronomy are said to be geometrical and physical (see *Tuḥfa*, f. 1r), the *Tadhkira* includes the additional metaphysical principles that "need to be proved" (see *Tadhkira* , p. 90); yet when Ṭūsī proceeds to explain these "definitions and principles," he subsumes them under two headings, namely geometrical and physical principles (*Tadhkira* , p. 92).

[6] The word "line" here is used to mean any line, whether straight or not.

The notion that a plane is generated when one line intersects another at each of its parts means that it is not enough to have two lines intersect to have a plane, but rather a plane is the space which is generated by two such lines. Similarly, solid bodies are generated by the intersection of surfaces and lines.

[7] The definitions of plane and solid, attributed to others, in this paragraph, are apparently ones with which Ṣadr is not satisfied, since they are not consistent with the definitions proposed in the preceding paragraph.

[8] If the concept of limit (*intihā'*) is used in a general sense to mean a bordering body or figure, then a solid would end in a plane, and the plane would end in a line or a point; hence, the solid could be said to end in a plane, line, or point, or simply in other than itself.

[9] This definition of line derives from the *Tadhkira* (see *Tadhkira* , p. 98). In it the Arabic word used for "points in the same direction" is *taḥādhā*, which is difficult to translate. According to Ṣadr's commentary, this definition of a straight line is apparently a circular one. Also objectionable is the definition of the *Tuḥfa* (see *Tuḥfa*, f. 1r), since the ray of sight comes out of the ocular soul which is a spot, and not a point. Therefore, the middle of a straight line, which has no width, could not cover its end, even if it falls along the ray of sight, since the field of vision within this ray is wider than a straight line.

[11] The objection raised in this paragraph against the definition of the plane angle in the *Tuḥfa* (see *Tuḥfa*, f. 1v) is to the use of the term configuration (*hay'a*), since, according to Ṣadr, an angle, be it plane or curved, is a surface which has a specific position, and hence has a specific dimension. This means that while the angle itself can be measured, and consequently can be divided, the configuration, which is a quality or property, admits neither measurement nor division. Therefore, a specific configuration of an angle is a resultant property of the angle, and not the angle itself.

[13] The word curved, translating Arabic *mustadīr*, is intended here to distinguish this kind of line from a straight line, otherwise the definition of a circle would be logically circular. The intended definitions are illustrated in figure 1.

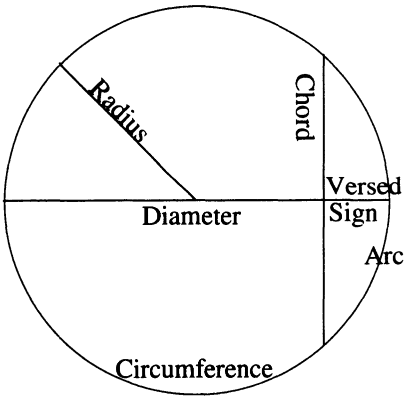


FIGURE 1

[15] The word orb in this paragraph is a translation of the Arabic word *falak*. The same word may occasionally be translated as a circle or a sphere whenever it is used in that sense (for a discussion of the meaning of the word, see Ragep's discussion in *Tadhkira* , pp. 378-9).

The definition of the orb in this paragraph needs further clarification. If the orb was transparent, then it cannot include any opaque body such as the earth, or even a planet, which are both defined as opaque. This, however, would mean that if the sphere of the planet is taken away from the spherical orb, then the orb would not be spherical any longer. A clarification expounded in the commentary is to posit that sphericity results from the convex and concave surfaces of the orb, even if the matter lying between them is not of the same nature (see *A*, f. 4r). These surfaces would be parallel when they include the earth, as distinguished from the two non-parallel surfaces of the complements--discussed later--or the surface of the epicycle which does not include the earth. And yet the epicycle is an orb.

[16] The traditional division of bodies into simple and compound is repeated in this paragraph. The simple nature of planets is, however, doubted. According to Aristotle the heavens and the stars are made of the fifth element ether which is of a simple nature (see Aristotle, *On the Heavens*, II, 7). A similar argument is maintained in *Tuḥfa* (see *Tuḥfa*, f. 7r), whereas in *Tadhkira* the simplicity is maintained without the mention of ether (see *Tadhkira*, p. 98). One reason for rejecting this principle, according to Ṣadr, is that we see spots on the face of the moon; for if the moon were of a simple nature, then there would be no variation in its appearance (see the earlier section of the *Ta'dīl* as in *W*, f. 186r-187r). Moreover, the objections referred to in the text are raised in regard to the sphericity of simple bodies. If such bodies were simple, then all their parts should be equidistant from the center. But in the case of a solid sphere such parts are not equidistant. One could then say that solid spheres could not be simple bodies, and only the outer shell of the sphere would be so. Apparently, the author wishes to define such spheres as simple despite this objection.

[17] The complete quotation from the *Tadhkira* is as follows: "the mobile is said to be self-moved if its principle of motion cannot become positionally separate from it. If it does separate from it, the movement is ascribed to the mobile" (see *Tadhkira*, p. 100). Ṣadr objects to this formulation because if the principle of motion is not positionally separate, then this means that it is positionally contiguous, which would thus exclude the case when a principle of motion has no position, or rather when it is not positionally defined (see *A*, f. 4v).

[18] In the commentary, the author spells out what he means by the word "restriction" by saying that the principle of natural motion is more general than the specific classification into linear and/or circular (see *A*, f. 4v). We thus have what seems to be a proper understanding of the revolutionary implications to the Aristotelian model brought about by Ṭūsī's couple, where linear motion can be produced as a result of two circular motions (on this subject see infra, De Vaux, and Kennedy, 1983, pp. 88-9; on this interpretation of the importance of Ṭūsī's couple and its utilization by Copernicus,

see Hartner, 1973). Therefore the natural motion of elements is not necessarily linear, and neither is the motion of celestial bodies necessarily circular, but a combination of both may occur.

[19] The movement of the orbs, according to Aristotle (*On the Heavens*, II, 8), Shīrāzī (*Tuḥfa*, f. 7r-7v), and Ṭūsī (*Tadhkira*, p. 100) is voluntary. The proof of this hypothesis, as Ṣadr understands it, is that the motion of the orb is neither natural nor by compulsion, and hence it must be voluntary. Ṣadr finds this proof extremely weak (see the earlier section of Ta'dīl as in *W*, f. 179r-186r). The author proceeds, however, to say that such a distinction is not essential for the astronomer, since it is only important to differentiate between those orbs which are moved by other orbs, and those which are not. This statement can be seen as an attempt to avoid addressing the physical, or even metaphysical, problematic question of the nature and cause of celestial motions. The author immediately proceeds, however, to address this question. An example of orbs moved by other orbs is the encompassed orb which is moved by the encompassing one. This example, however, is itself problematic, since such a movement is necessitated in either one of two cases: the first case is when the encompassed orb is eccentric. In this case, the two orbs are physical bodies, and their complementary surfaces are not parallel. Therefore, when one of these bodies moves, the second one must follow in motion. If such motion does not follow, then the two solid bodies would cut through each other, or the surfaces of the sphere would be deformed.

The second case in which the movement of the encompassed orb becomes necessary is when the pole of the encompassed orb is attached to and seeks a specific point on the encompassing one. Thus if the encompassing orb moves, then the pole of the encompassed one follows the point which it seeks, and thus moves with it the whole orb.

Ṣadr objects to the above hypothesis on the ground that if the encompassing orb is simple in nature, then no point in it would be different from its other points, such that it alone would be sought by the pole of the encompassed orb. Moreover, if this hypothesis is granted, then we still need to explain the motions of the orbs of such planets as Saturn whose poles are not attached to any point of the great orb. Thus the movement of the orb of Saturn does not directly follow as a result of the movement of the great orb, nor does it follow indirectly as a result of the intermediary movement of the zodiacal orb, since the poles around which both orbs rotate coincide (see *A*, f. 5r).

[20] Shīrāzī also objected to the hypothesis explained in paragraph 19 (see *Tuḥfa*, f. 39r, 39v, and *Nihāya*, f. 33r, 33v, 34r). In its place he proposes that the cause of motion is the strength of the soul of the encompassing orb. Thus if this soul is strong enough, then it will move the encom-

passed orb irrespective of whether the orbs are eccentric, or whether the poles of the latter orb are attached to some specific point of the former one.

[21] Ṣadr rightly notices that Shīrāzī's assumption of voluntary souls does not explain how the motion is uniformly transmitted from one orb to the other. Moreover, Ṣadr adds that, according to Shīrāzī's hypothesis, since the encompassed orb has its own motion ,it must have its own soul. But the soul of the encompassing orb is also attached to the encompassed one. Therefore, the encompassed orb would have two souls, which, according to Ṣadr, is a hypothesis that no one would maintain. If, on the other hand, the soul of the encompassing orb were not strong enough, then, contrary to what Shīrāzī maintains, a physical instrument would be needed to impart motion.

[22] Having noted that Shīrāzī's method does not explain how the movements of the planets by their parecliptics are possible, when these parecliptics are concentric with the great orb, Ṣadr moves to propose that the only solution to this problem is to assume that the parecliptics themselves are eccentric. If the eccentricity is small enough, Ṣadr maintains, then the difference in motion between the parecliptic and the great orb, as seen from the earth, would not be detectable. Yet if we were to accept this position of the author, then it would be impossible to explain the movement of the planets by their parecliptics, since these no longer represent the ecliptic itself, which is the source of motion in the first place. Moreover, to have an eccentric parecliptic is a contradiction in terms, since the parecliptic, by definition, is an orb that represents the ecliptic and is concentric with it. Thus, no matter how small this proposed eccentricity is, it cannot be theoretically accepted, and Ṣadr's proposition does not constitute a solution for the above problem.

According to Ṣadr's proposed solution, only one parecliptic is needed to represent the great orb, and each planet has a separate eccentric orb embedded within it. Each of these planets thus has an individual motion caused by the same parecliptic. The moon is an exception, because its parecliptic is the orb of its nodes, and these nodes have a separate motion which is different from the motion of the great orb. The two surfaces of the upper complementary solid of the great orb, which is the space between the great orb and its eccentric parecliptic, are not parallel. On the other hand, the two surfaces of the moon's special parecliptic are parallel. Therefore, the resulting configuration does not have parallel surfaces, and the movement of the great orb is thus transmitted, through the moon's special parecliptic, to the moon itself. The complementary solids are not orbs; rather they are spaces enclosed between surfaces of different orbs. The total number of orbs is seven orbs embedded within the great one.

[23] This section is problematic and incomprehensible. Implied in it, however, is the notion that fixed stars do not necessarily belong to one sur-

face, and that some stars may fall below Saturn. Furthermore, this means that stars and planets may be embedded at different distances within the great orb, thus allowing for the intermingling of spheres, which accounts, according to Ṣadr, for the second motion, presumably of the parecliptic of Saturn. This assumption is contrary to what is known about Saturn. Moreover, it is not consistent with what Ṣadr himself elaborates in the rest of his astronomy (see infra, the discussion of Saturn).

CHAPTER 2

[3] The first proof which Ṣadr gives for the sphericity of the celestial orb is that the paths of the stars, during their daily rotations, describe circles which are parallel to each other, and which have the north pole, or rather the polar axis, as their fixed axis of rotation. That such paths are circular, and that these circles are parallel, could easily be verified by simple observation. Moreover, the closer a star is to the pole, the smaller the described circle would be. A cylindrical shape is ruled out, since the described circles under such an assumption would be equal in size. As further evidence for the sphericity of the celestial orb, Ṣadr adds that the visibility of the abovementioned circles varies in accordance with the specific properties of the sphere. A star in the vicinity of the pole never becomes invisible. In other words, the circle which this star describes does not intersect the local horizon, and thus it is always in the visible half of the celestial sphere. On the other hand, a star which is farther away from the pole, and whose path intersects the local horizon, becomes visible only for a part of its rotation, and invisible for the rest of it. As we move away from the pole, the section of the circle which is invisible increases in size, until it reaches a point where the visible and the invisible sections become equal. The circle thus described is the circle of the equator. Beyond this circle, the invisible part becomes larger than the visible one, and finally the whole circle disappears. Two small circles of the celestial sphere, which are equidistant from the equator, are symmetrical around the center of the sphere, and it can easily be shown from that point how the visible part of the first of these circles, i.e. the part above the horizon, equals the invisible part of the other circle, i.e. the part below the horizon.

Further evidence given by Ṣadr for the sphericity of the celestial orb, is the gradual, or rather uniform rising and setting of the stars. It is not clear, however, how such a point can be taken as evidence for sphericity. More relevant is the observation that the bodies of stars have equal apparent sizes, which implies that they are equidistant form the center of the world, and that they are located on the surface of a sphere. Ṣadr notes, however, that on the horizon, stars appear to be bigger due to vapors; in other words, Ṣadr wrongly attributes this phenomena to refraction, while in fact it is nothing but an optical illusion.

Final evidence for the sphericity of the celestial orb is that one half of the orb is always visible to an observer on the earth. There is, however, according to Ṣadr, an exception to the above rule. In his commentary, Ṣadr mentions that this exception is in the case of the orb of the moon, since less than one half of this orb is actually visible (see *A*, f. 6v). This is due to the paral-

lax phenomenon which is negligible for the stars and the planets. In the case of the moon, however, the ratio of the radius of the earth to the distance between the earth and the moon is large enough to be sensed by an observer at the surface of the earth. Hence, the apparent position of the moon as it crosses the local horizon, is lower than its true position. Moreover, the part of the orb of the moon that is seen is actually less than half of it. (on parallax theory in Islamic astronomy, see Kennedy, 1983, pp. 164-184).

Before moving to the next paragraph, it may be useful to say a word about Ṣadr's method of addressing the question of sphericity. Although there are clear similarities between this chapter and the corresponding chapter in Ptolemy's *Almagest* (see *Almagest*, Book I, sections 3-7), Ṣadr seems to be working more along the lines of Ṭūsī and Shīrāzī. He first incorporates Ṭūsī's procedure without explicitly mentioning his name, then he raises some questions that are not answered in this approach, and finally he introduces Shīrāzī's method, together with what he finds objectionable about it. As in Ṭūsī, Ṣadr differs from Ptolemy in that he only uses observational evidence to address the question of sphericity (on the difference between Ṭūsī and Ptolemy, see *Tadhkira*, p. 382). Ptolemy, on the other hand uses observation to suggest the possibility of sphericity, but his proofs are based more on physical principles pertaining to the qualities of ether and the difference between circular and rectilinear motions.

[4] As in Ṭūsī, Ṣadr gives as a first proof for the sphericity of the earth, the earlier rising and setting of the sun in an eastern locality as compared with a western locality (see *Tadhkira*, p 103-5). Ṣadr, however, adds that the proof for the above is the difference in the times of the midpoint of the same lunar eclipse. A similar addition can be found in the *Tuḥfa* (see *Tuḥfa*, f. 8v). The proof is as follows: since a lunar eclipse takes place when the earth falls between the sun and the moon, then the midpoint of this eclipse is observed by different observers in different localities on the earth at the same time. Now if the occurrence of such an eclipse is taken as a time reference, then the setting of the sun in an eastern locality is further away from the time of the eclipse than its setting in a western locality. This proves that the setting of the sun in an eastern locality is earlier than in a western one. And similarly for the rising of the sun. Therefore, the earth cannot be flat, since the times of rising and setting would then be the same for all localities, and thus the line along the surface of the earth, which passes through the east and west points, cannot be rectilinear.

Next, Ṣadr states that a traveler toward the north, along the north-south line, notices an increase in the culminating altitude of a northerly star, and in the depression of a southerly star, and conversely for a traveler toward the south. This is so because as one heads north, the north pole comes closer to the zenith, which is right above the observer, and a northerly star thus approaches this zenith, and appear to have a higher altitude. Therefore, the

line along the surface of the earth, which passes through the south and north points, is not rectilinear.

Finally, if one travels along some intermediary direction, that is along a line which falls somewhere between the east-west and south-north lines, then the above effects are compounded.

[5] Ṣadr notes rightly, however, that the above argument does not conclusively prove that the earth is spherical, for it is still possible to have the distance between the north and south points longer than the distance between the east and west points. Thus we may have either an oval or a lenticular shape instead of a sphere.

It is clear that Ṣadr, in the preceding few paragraphs, is not expressing his own point of view, in as much as he is presenting the general point of view as expounded by Ṭūsī. After mentioning his reservations, Ṣadr moves on to explore the proofs given in the *Tuḥfa*.

[6] In the *Tuḥfa* (see *Tuḥfa*, f. 8v-11v), Shīrāzī proceeds in reverse; he first uses arguments similar to those already introduced to prove that the earth is spherical. Next, he builds on this first step to prove, "through observation," that the surface of the celestial orb is parallel to that of earth, and that it too is spherical. Shīrāzī's method is as follows: consider two localities of equal latitudes and varying in longitudes. Let the difference in longitude between these two localities, measured along the celestial orb, be some amount x, and let the distance between the two localities, measured along the surface of the earth, be some amount y. Next consider two other localities which have equal longitudes and different latitudes. Let the difference in latitude between these be x', and the distance between them be y'. Shīrāzī maintains that the ratio of x to y is equal to the ratio of x' to y', thus proving that the surface of the celestial orb is parallel to that of the earth, and is therefore spherical.

[7] Ṣadr objects to the above method by noting that, even if we were to believe that the land surveyors actually made such measurements, and obtained such results as the ones claimed in the above paragraph, we still cannot prove that all other measurements that we may make in other localities on the surface of the earth, would yield the same results. This reservation seems to apply to the northerly localities which were not accessible to people due to the extreme cold weather which prevails in them (see *A*, f. 7v). Thus to account for such localities, Ṣadr maintains that one further point needs to be added, namely that a traveler moving toward the north, along any great circle which passes through the south and north poles, records a change in the altitude of the pole which is equal to the change of the depression of a star as measured from the zenith of the respective locality of this traveler. If this were so, then the parts of the celestial orb which correspond to the parts of the earth which are not inhabited, and thus not surveyed, must be spherical.

[8] Ṣadr raises in this paragraph another objection against Shīrāzī's method; the above qualification introduced by Ṣadr applies only to the celestial orb, and does not apply to the earth, since it is still perceivable that those parts of the earth which were not surveyed may be longer or shorter than those parts which were proven to be spherical. And even in the case of the celestial orb, we cannot rule out the possibility that this orb has the shape of a polygon which approximates a circle, but is not one, or that the surface of the celestial orb might have certain indentations which cannot be detected by an observer on the earth.

One thus has the impression that, although neither Ṭūsī nor Shīrāzī resorted to physical arguments to infer the sphericity of the earth and the celestial orb, they nonetheless had such arguments in their minds. Ṣadr, on the other hand, seems to rely solely on observational evidence, which eventually makes him doubt, though not reject, this long accepted hypothesis of sphericity.

[9] The contents of this paragraph are self explanatory. It is worth mentioning, however, that this proof for the sphericity of the surface of the water is not the proof given in Ptolemy's *Almagest*, nor is it the main proof in either the *Tuḥfa* or the *Tadhkira*. Ṣadr's objection to these proofs is discussed in the next paragraph.

[10] As mentioned above, Ṣadr is responding here to the proof given by Ptolemy (see *Almagest*, I, 4, p. 41), which is also used by Ṭūsī (see *Tadhkira*, p. 105) and Shīrāzī (see *Tuḥfa*, f. 9r). Ṣadr, in this paragraph, wrongly denies that the convexity of the surface of the water affects visibility. He adds that the change in the appearance of a mountain results from the fact that we see objects smaller at far distances; thus at such distances we think that we only see the tip of a mountain, while in reality we see the whole of the mountain, but in smaller size. Moreover, Ṣadr invokes the notion of optical illusion when he claims that the vapor of the sea obscures the bottoms of the mountains.

[11] In this and the following paragraphs Ṣadr makes a passing reference to the theoretical principles, both physical and mathematical, which were used by his predecessors, and hastens to reject them. He first dismisses the argument for the sphericity, based on the physical principles, as irrelevant, since such an argument only applies to a simple body which is left to its nature. The surface of the earth is neither simple, nor is it nor is it left to its nature.

[12] The mathematical argument that the proportion ρf the indentations of the surface of the earth to its size is negligible, and does not detract from the fact that the earth is spherical, is one to which Ptolemy alludes (see *Almagest*, I, 4), and which is picked up and elaborated in both the *Tadhkira* (see *Tadhkira*, p. 105) and the *Tuḥfa* (see *Tuḥfa*, f. 9r). According to Ṣadr,

the approximation of the earth to a sphere is in itself equivalent to saying that it is not one.

[13] If the above mentioned approximation is simply to say that the celestial phenomena, which are observed from the surface of the earth, do not change as a result of the indentations along this surface, then Ṣadr rightly concedes that such approximation is valid.

[14] Having presented the evidence for the sphericity of both the celestial orb and the earth, Ṣadr moves here to prove that the earth is located at the center of the celestial sphere. To establish this centrality, Ṣadr, like his predecessors (see *Almagest*, I, 5; *Tadhkira*, p. 105; and *Tuḥfa*, f. 11v-12r), proceeds to prove that the earth is simultaneously the midpoint of the east-west line, the south-north line, and the line between the above and the below. The first point is inferred from the fact that, for any star that rises and sets, the time from its rising until it reaches its highest point (that is, when it crosses the meridian circle,) is equal to the time from this highest point until the setting of the star. The fact that, when the sun is at the equinox, the westward shadow which is cast by the rising sun coincides with the eastward shadow which is cast by the setting sun, proves that the sun is half way between the south and the north points. This is also inferred from the coincidence of the shadows cast by the rising when the sun is at a certain position and by the setting when the sun is at a position which is symmetrical to the first one with respect to the equinox. Finally, the fact that half the celestial sphere is always visible, indicates that the earth is halfway between the above and the below of the sky. A more general proof for the centrality of the earth, according to Ṣadr, is that the earth eclipses the moon when the latter has no latitude, and is in opposition to the sun. Ṣadr implicitly assumes in this last proof that the lunar eclipse takes place when the moon and the sun are diametrically opposite; so for the earth to fall between the two, it must coincide with the center of the celestial sphere. Ṣadr, however, does not verify this assumption, and does not supply enough justification for ruling out the possibility that the moon and the sun may not be in the ecliptic plane. (For an illustrated proof of the above, see Pedersen, pp. 39-42.)

[15] This is the second reference that Ṣadr makes to the parallax phenomena in this section (see paragraph [3] above). Similar proofs are given by Ptolemy (see *Almagest*, I, 6), Ṭūsī (see *Tadhkira*, p. 107), and Shīrāzī (see *Tuḥfa*, f. 12r).

[16] Ṣadr's proof that the earth is stationary is the simple fact that when we throw a stone into the air, it falls back onto its original point of departure. Ṣadr is obviously referring to a stone which is thrown vertically upwards. The differences in the proofs given by Ṣadr's predecessors are of interest, and may be indicative of the process of thinking of these astronomers. Ptolemy, on the one hand, proves that the earth is stationary by

employing the Aristotelian theory of gravity (for the original theory see Aristotle, *On the Heavens*, II, 14; on Ptolemy's use of this theory see *Almagest*, I, 7; and Pedersen, pp. 43). He then rejects the idea that the earth, together with the layer of air surrounding it, could be rotating, since in this case a stone thrown vertically upward would fall back onto its original position, while in reality it does not. It has already been noted that this argument is weak, and it confuses vertical motions with projectiles (see Pedersen, p. 44). This discrepancy in Ptolemy must have been noted by Ṭūsī, who rejects the whole notion of proving the stillness of the earth from an observation such as that of the stone. Indeed, Ṭūsī adds, the stone might fall back onto its original position due to the concomitance of the air and the earth. This phenomena would be similar to that of the concomitance of the ether to the celestial sphere, which accounts for the motion of comets. Thus, according to Ṭūsī, the only way to prove that the earth is stationary is by using the physical principle of the rectilinear tendency of the earth, which implies that the earth, by nature, cannot have a circular motion (see *Tadhkira*, pp. 107). Shīrāzī rejects this last proof for several reasons; he first states that the principle of concomitant motion (*mushāya'a*) between the ether and the celestial sphere is not permitted, and that the motion of the comets is due to a soul rather than to such concomitance (see *Tuḥfa*, f. 15r). Next he states that had this principle of concomitance been valid, then the movement of a heavier object would have been smaller than that of a lighter one (see *Tuḥfa*, f. 15v). Moreover, the argument of the natural philosopher, according to Shīrāzī, is not valid, since even if the nature of the earth does not entail its rotation, it can still rotate by compulsion. Thus the only valid proof is an observational one, namely that of the stone which, when thrown vertically upward, falls back onto its original position. Ṣadr, on the other hand, uses an argument similar to that of Shīrāzī to show that the principle of concomitance does not hold. The major difference between the two, however, is in that, while the latter resorts to observational evidence only because the physical evidence would not apply, the former's choice seems to be a matter of preference and approach.

[17] In the preceding paragraphs Ṣadr addressed the question of the sphericity of the celestial orb, the earth, and the water. A number of reservations that Ṣadr had concerning some of the common theories were pointed out in the above commentary. In this section, Ṣadr has some more reservations to express; he starts by stating that it is problematic to say that the earth is in the middle. This is so because the surface of the water has to be equidistant from the center of the world, by virtue of its fluidity. Moreover, in order that the water does not flow and cover the surface of the earth, the sum of the earth and the water taken together should be either equidistant from the center of the world, or the water should be closer to the center.

Thus the sum of the earth and the water, taken together, constitutes one sphere, whose center is the center of the world.

It is not clear whether Ṣadr considers this last suggestion of one whole sphere as a solution of the above problem, or whether he is simply restating it, since we still have two contradictory propositions, namely that the center of the water should be the center of the world, and that the center of both the earth and the water should be that center as well. It is clear, however, that Ṣadr does not approve of considering the center of the earth alone to be the center of the world.

[18] Ṣadr seems here to be responding to an argument which maintains that the excessive heat of the sun would curve the water and prevent it from flowing.

It is not clear to the me who the argument in this paragraph refers to. As far as I could tell, there is no such idea promoted in either the *Tadhkira* or the *Tuḥfa*, nor could I find a parallel view in the *Almagest.*

[19] The idea of this paragraph is of little importance to the subject of this chapter, and it seems to be mentioned simply on account of its strangeness, which is exactly why it was also mentioned by both Ṭūsī and Shīrāzī (see *Tadhkira*, p. 107; and *Tuḥfa*, f. 10r).

[20] This paragraph, and the two to follow, have their parallels in both the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, p. 111-3, and *Tuḥfa*, f. 19v-20v). The major difference between these corresponding sections, however, is that they are subsumed in the above two works under the chapter on the "arrangement and order of heavenly bodies', while in Ṣadr they follow the discussion of the earth. This different order is not without significance, for the question of the elements and their different combinations could easily lead the author into the domain of the physical sciences which he tries to avoid. Nevertheless, Ṣadr could not simply neglect mention of those elements, since he includes them in his definition of the science of astronomy, and also because of the well established tradition before him which sets the paradigms for his work.

At first, Ṣadr seems to pick up one paragraph from the *Tadhkira* and the next from the *Tuḥfa*. A close examination, however, indicates an attempt by Ṣadr to complement whatever is missing in one by additions from the other. Moreover, some subtle modifications of the borrowed ideas are quite revealing of Ṣadr's attempts. One example of such a modification is the authors reference to the mixed layer of air and fire, in which comets are found. The Arabic word for "are found" is "*takūn*". The corresponding word used by Ṭūsī is "*tatakawwan*", which means "are formed" instead of "are found'. It is my belief that this difference is not a simple scribal error, but rather an intended deviation in which Ṣadr describes the phenomena of comets, without attending to the Aristotelian question of how or where such comets are formed.

[21] This section is not found in the *Tadhkira*, and is an abridged version of the corresponding section in the *Tuḥfa* (see *Tuḥfa*, f. 11v-12v), and although it hints at the related but not equivalent problem of the height of the atmosphere, it does not directly address this problem. The approximation of the height of the atmosphere to seventeen leagues, which is equal to fifty one miles, is very close to the figure given by Shīrāzī in the *Nihāya*, which is 51;58 miles (on "The Height of the Atmosphere.." see the article by George Saliba in King and Saliba, pp. 445-466).

[22] It is partly understandable that Ṣadr does not dedicate a separate section to introduce the different planets, since this is the concern of most of the remaining part of the work, and since these planets are discussed in detail in the following chapters.

CHAPTER 3

[1] The material covered in this section under the title "on circles" is covered in Ptolemy's *Almagest* under the title "that there are two different primary motions in the heavens" (see *Almagest*, I, 8). In the *Tadhkira*, the same material is covered in two different chapters entitled "concerning the well-known great circles" and "concerning the circumstances that occur due to the first two motions, and the situation of the fixed stars" (see *Tadhkira*, pp. 113-29). These correspond to two similar chapters in the *Tuḥfa* (see *Tuḥfa*, f. 21r-50r). This difference further illustrates the difference in approach among the four authors; at one extreme is Ptolemy's concern with motion, while at the other extreme is Ṣadr's concern with the geometric representation, and in between is a rather balanced concern with both issues in question.

[2] The outer sphere in figure 2 is the great orb. This orb rotates daily from the east to the west around the axis *SON*. Point *O* is the center of the great orb, and is thus the point where the earth is located. Point *N* is the north pole, and point *S* is the south pole. The great circle which rotates around center *O*, and which is perpendicular to the axis of rotation is called the equator circle; this is circle *AEBW*. A point on this circle completes a full revolution in approximately one full day and night. The word "approximately" is used because what we observe as one day and night is the difference between the rotation of the sun, together with the great orb, around the axis of rotation, and the smaller motion of the sun along its own path (see infra).

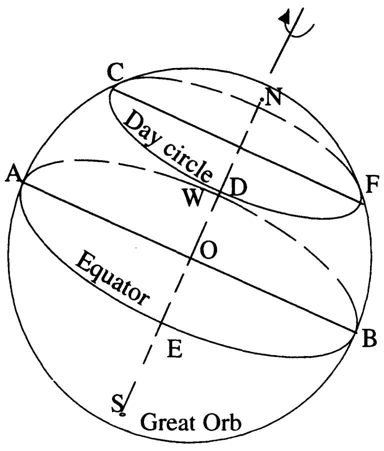


FIGURE 2

Any point on the great orb would inscribe, as a result of the daily rotation of this orb, a small circle which is parallel to the equator circle. *CDF* is one such circle, and is called a day-circle.

In the corresponding sections in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, p. 113, and *Tuḥfa*, f. 21v), the authors start by saying that the cincture of the first motion is the great circle which is called the equator circle. This definition of the equator is made without explicit mention of the motion of the great orb, although it is the motion that is being referred to. A possible reason for this evasive definition might be the attempt to avoid addressing the question of whether the great orb and the ecliptic orb coincide or not (see infra).

[3] The outer sphere in figure 3 is the ecliptic orb. This orb is the sphere which carries the fixed stars, and it rotates around axis *IOJ* from the west to the east, that is in a direction opposite to the above mentioned daily rotation. The great circle which rotates around center *O*, and which is perpendicular to axis *IOJ*, is called the zodiacal belt, or the ecliptic circle; this is circle *GEHW*. According to ancient astronomers (i.e. Ptolemy), a point on this circle completes a full revolution in thirty six thousand years (i.e. a precession of 1 degree/100 years; see Pedersen, p. 248,), whereas latter astronomers had determined this period to be twenty four thousand years (i.e. 1 degree/66 years).

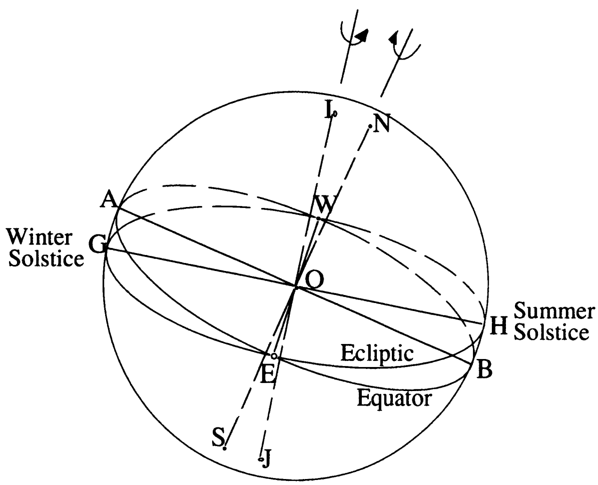


FIGURE 3

It is usually assumed that the great orb and the ecliptic orb are the same (although strictly speaking they are not), in which case the equator circle

and the ecliptic circle intersect, as in figure 3, at the two points *E* and *W*. A point on the equator thus rotates in the direction of *EAWB*, while a point on the ecliptic rotates in the direction of *WGEH*. Moreover, Line *EW* passes through the center *O*. Point *E* is called the vernal equinox and point *W* is the autumnal one. When a planet which is moving along the ecliptic crosses point *E*, it passes to the north of the equator; and when a planet crosses point *W*, it passes to the south of the equator. Point *H*, which is the midpoint of the section of the ecliptic that is north of the equator, is called the summer solstice, and point *G*, which is the midpoint of the section that is south of the equator, is called the winter solstice.

Here also, the corresponding section in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, pp. 113-5, and *Tuḥfa*, f. 21v, 22v, 34r) refer to the cincture of the second motion rather than to the motion of the ecliptic orb. Thus in these two works the ecliptic and the equator circles always intersect, whereas in Ṣadr, these two circles only intersect if the ecliptic and great orbs are assumed to coincide. One may thus note with Ṣadr that the question of representation is not a definite and final one, and that there could be alternative representations.

[4] The outer sphere in figure 4 is the great orb, which coincides with the zodiacal orb. Circle *GEHW* is the ecliptic, and circle *AEBW* is the equator. With two points we divide each quadrant of circle *GEHW* into three equal parts. The ecliptic circle is thus divided into twelve equal parts by twelve points, through which six great circles can be drawn perpendicular to the ecliptic circle. These six circles all intersect at the poles I and J, and one of them passes through the poles of the equator circle and through the two solstices; this is circle *IGSJHN*. The inclination of the ecliptic is defined as the arc of this last circle which lies between the equator and the ecliptic circles, that is either arc *AG* or arc *BH*. It is clear from the figure that the above two arcs are also equal to arcs *IN* and *JS*.

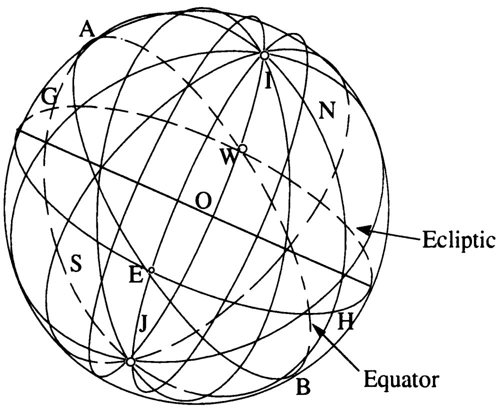


FIGURE 4

The six great circles divide the ecliptic orb into twelve equal strips, each extending between the two poles *I* and *J*, and each having a longitude of thirty degrees, measured along the ecliptic circle. These are the twelve zodiacal signs of the ecliptic orb.

Ṣadr claims to have measured the inclination of the ecliptic and found it to be 23;33 degrees, in conformity with the *'Alā'ī zīj*. This latter *zīj* is not extant but is an influential work in Arabic astronomy. It is attributed to 'Abd al-Karīm al-Shirwānī al-Fahhād, and was written around the middle of the sixth century A.H. (12th century A.D.). It is possible, however, to confirm the above measurement of the inclination of the ecliptic from the parts of the *'Alā'ī- zīj* which were preserved in the astronomical works of Gregory Chioniades who reproduced major sections of this work (on the reconstruction of the *'Alā'ī zīj* out of the work of Chioniades see Pingree, pp. 7-29; also see p. 195 of the same work for a reference to the inclination of the ecliptic). In this extant version, however, the inclination of the ecliptic is given as 23;35, and not as quoted by Ṣadr. Therefore, Ṣadr may have seen a text different from the one read by Chioniades.

The corresponding sections in the *Tadhkira* and the *Tuḥfa* have basically the same material as in this paragraph (see *Tuḥfa*; f. 22v-23v, and *Tadhkira*, pp. 113-5, 117).

[5] This paragraph has an equivalent in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, pp. 115, 125, and *Tuḥfa*, f. 24r). It refers to the progressive precession of the ecliptic orb, and hence the ecliptic circle, with respect to the great orb, and hence the equator circle. The fixed stars are fixed on the ecliptic orb, which means that their positions with respect to each other do not vary. The position of the whole ecliptic orb, however, moves relative to

the great orb in the motion referred to as the second motion. To measure this motion, the configuration of the fixed stars, at some initial position, is plotted on the great orb. The ecliptic circle and the equator circle, while the former is at this position, intersect at the equinoctial points. These points are then taken as fixed reference points against which the motion of the ecliptic is measured. As a result one can think of strips along the ecliptic being assigned names of the constellations, whereas the real constellations have departed from their original locations with respect to the ecliptic.

[6] The sections in the *Tadhkira* and the *Tuḥfa* which correspond to this paragraph are strikingly similar to it, especially the former one (see *Tadhkira*, pp. 125-7, and *Tuḥfa*, f. 40r-41v). Consider in figure 5 the outer sphere to be the great orb, with the equator circle $AEBW$, and the ecliptic circle $GEHW$. Consider any star P on the ecliptic orb, which has the same size and center as the great orb, and draw through P the great circle which passes through the poles I and J of the ecliptic, and which is perpendicular to it. Let this circle intersect the ecliptic at point Q. Arc PQ, measured on this circle, is called the latitude of the star. As a result of the second motion, star P traces on the great orb a circle which is parallel to the ecliptic circle. This is called the latitude circle and it varies with the variation in the latitude of the star; if the latitude is zero, then P coincides with Q, and the path is along the ecliptic itself. The latitude circle intersects the equator circle twice in this first case. If the latitude P_2Q is greater than zero but less than the inclination of the ecliptic, then the latitude circle also intersects the equator twice, but the north and south sections of this circle would not be equal; if the planet is north of the ecliptic, then the northern section of the latitude circle is greater than the southern section and vice versa. If the latitude P_3Q is equal to the inclination of the ecliptic, then the latitude circle intersects the equator at only one point. If the latitude is greater than the inclination of the ecliptic, then the latitude circle, and hence the star itself, does not intersect the equator, but rather approaches and recedes from it. If, finally, the latitude P_5Q is equal to the complement of the inclination of the ecliptic, then arc IP_5 would be equal to the inclination of the ecliptic, which is also equal to the angle ION. Now since the latitude circle rotates around the axis OI, and since angle ION equals angle IOP_5, the latitude circle passes through the pole of the equator, which means that a star whose latitude is the complement of the inclination of the ecliptic reaches the pole once every complete revolution.

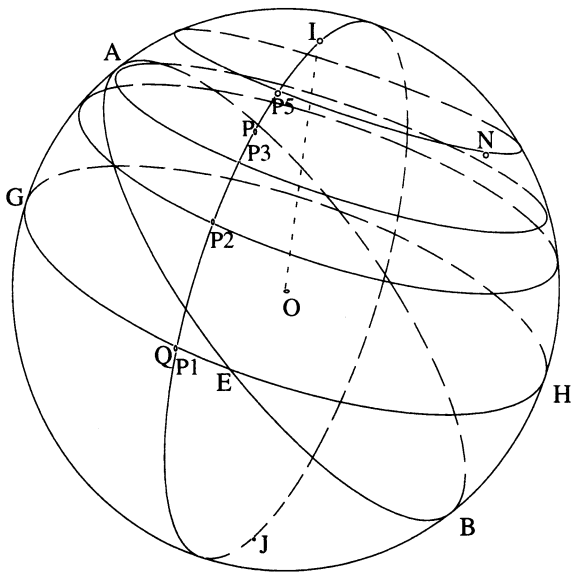


FIGURE 5

Now since the distance of a star from the equator circle depends on its position along its latitude circle, the daily circle described by this star would also vary according to this position.

[7] To illustrate the point of this paragraph consider in figure 6 the big circle *PAB* to be the celestial orb, and the small circle O_1O_2 to be the earth. The circles are concentric at *O*. An observer located at point O_1 has a horizon which is tangent to the earth at O_1, and which intersects the celestial sphere at *A* and A_1. Although drawn here on the surface of the earth for illustrative purposes, horizon AA_1 is in effect indistinguishable from the diameter passing through point *O*. For the above observer, a star *P* on the celestial orb appears to have an altitude *AP* above the horizon. To another observer, located at a point O_2, the same star *P* appears to have an altitude *BP* which is clearly different from *AP*. Hence, the difference in the apparent positions of the stars.

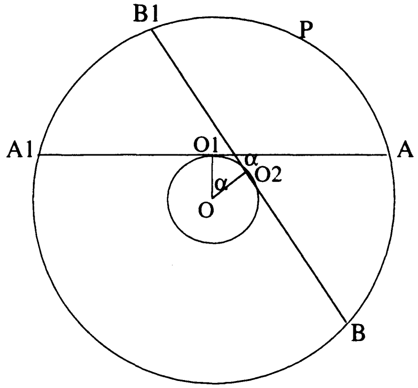


FIGURE 6

[8] To illustrate this paragraph, which has its equivalent in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, pp. 117-9, and *Tuḥfa*, f. 26r-26v), consider the outer sphere in figure 7 to be the celestial sphere; a plane drawn through any point on the surface of the earth tangent to this surface, is the local horizon of that locality; let this horizon plane intersect the celestial sphere in the horizon circle *LEMW*. Since the radius of the earth is very small compared to the radius of the celestial orb, the tangent to the surface of the earth is effectively equivalent to the parallel plane which passes through the center of the world, namely point *O*. The horizon circle can thus be assumed to coincide with the great circle drawn through point *O* parallel to the proper horizon.

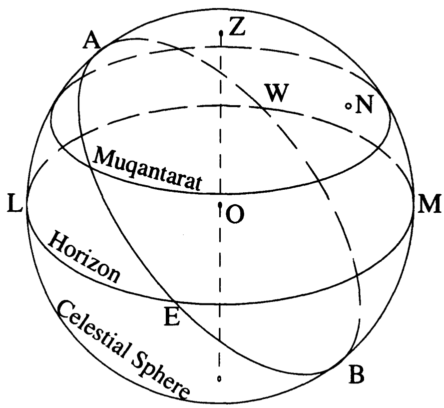


FIGURE 7

The region above the horizon plane is visible, whereas the region below it is invisible. The perpendicular to this plane drawn through point O intersects the celestial sphere at its two poles, Z and K; point Z is called the zenith, and point K is called the nadir. Moreover, the equator circle and the horizon circle intersect at the east point E, and the west point W; line EW is the east-west line. Finally, the small circles drawn parallel to the horizon circle are called *muqanṭarāt*.

[9] Consider in figure 8 circles $AEBW$ and $LEMW$ to be the equator and horizon circles respectively. The great circle which passes through the zenith and the nadir, and through the east and west points is called the primary vertical; this is circle $ZEKW$, and is clearly perpendicular to the horizon plane. On the other hand, the great circle which passes through the zenith and the nadir, and through the two poles of the universe, is the local meridian; this is circle $NZSK$ which intersects the horizon circle at points L and M, and intersects the equator circle at points A and B. The meridian is clearly perpendicular to the equatorial and horizon planes. Point M is the north point, and point L is the south point, and line LM is the midday line. Moreover, arc ZA is equal to arc MN, and both are equal to the terrestrial latitude.

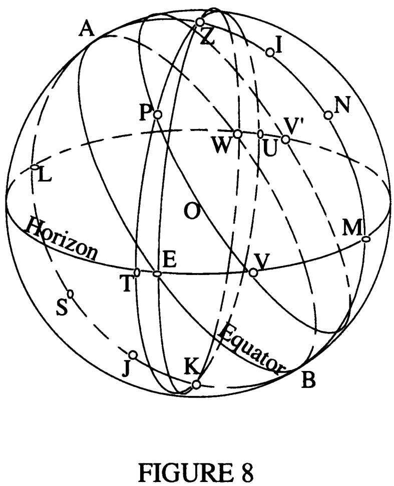


FIGURE 8

The arc of the great circle which passes through the zenith and the nadir, and through the two poles of the ecliptic between the zenith and the ecliptic is called the midheaven of visibility; this is arc IZ, and it coincides with the

meridian circle as long as the positions of the poles of the ecliptic and the value of its inclination of the ecliptic are considered to be fixed.

Finally, a great circle passing through the zenith and the nadir, and through any given star P on the celestial orb is the altitude circle of that star. Let this be circle ZPK, and let it intersect the horizon circle at T and U. If point P is below the horizon, then arc PT is called the depression of star P; if it is above the horizon, then arc PT is its altitude. Arc TE, measured on the horizon circle, is the azimuth of star P. Now if we draw through point P a small circle parallel to the equator circle, such that it intersects the horizon circle at points V and V', then arc EV is the rising amplitude of the star P, and arc WV' is its setting amplitude (for the corresponding sections in the *Tadhkira* and the *Tuḥfa*, see *Tadhkira*, pp. 119-21, and *Tuḥfa*, f. 27r-29v).

[10] A slight ambiguity in this section is easily resolved by reference to the *Tadhkira* or the *Tuḥfa* (see *Tadhkira*, pp. 115-7, and *Tuḥfa*, f. 25r-25v). Consider in figure 9 circles $AEBW$ and $GEHW$ to be the equator and ecliptic circles respectively. Point P corresponds to any star on the celestial orb. The great circle which passes through the poles of the equator and through point P is called the declination circle; this is circle NPS, and it intersects the equator at point X and the ecliptic at point X'. The great circle drawn through the poles of the ecliptic and the point X' is the latitude circle of that point; this is circle $IX'J$, and it intersects the equator circle at point X''. Arc PX, measured along the declination circle is the distance of the star from the equator, whereas arc XX', measured along the same circle, is the first declination of point X'. Arc $X'X''$, measured along the latitude circle, is the second declination of point X'. Since circle $NPXS$ is perpendicular to the equator circle $AXEBW$ at X, therefore angle $X'XX''= 90°$. Now in triangle $X'XX''$, angle X is a right angle, therefore $X'X''$ is the hypotenuse of the triangle, and $X'X''$ is greater than $X'X$; thus the second declination of any point on the ecliptic is greater than its first declination. This is obviously true as long as this point of the ecliptic does not coincide with either one of the two solstices; in the latter case, the declination circle and the latitude circle coincide, and the first and second declinations will be equal.

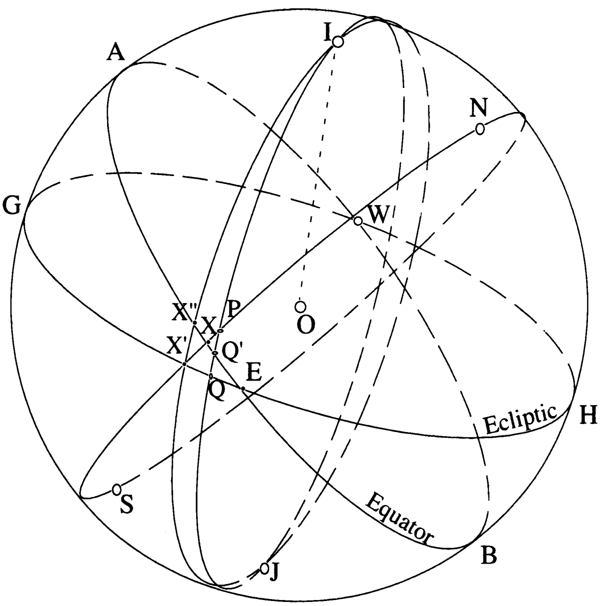


FIGURE 9

If, on the other hand, the latitude circle is drawn through the star *P*, and if it intersects the ecliptic circle at point *Q*, then arc *PQ* is the latitude of this star.

[11] In this section Ṣadr, like his predecessors (see *Tuḥfa*, f. 32r-33r, and *Tadhkira*, p. 121), notes that the inclination of the ecliptic has been observed to vary. This variation, however, is not uniform; thus, according to Ṣadr, it may result from errors in the observational instruments. Yet if this were true, then these same instruments should produce erroneous observations when used to measure the latitudes of planets, for example. Therefore, Ṣadr concludes, it is more likely that this observed variation corresponds to a real change in the inclination of the ecliptic, and not to some error in its measurement.

[12] Following the previous paragraph, Ṣadr mentions here the proposition that the ecliptic moves in latitude (i.e., the angle between the ecliptic and the equator varies.) Although this assumption has little physical significance, Ṣadr nevertheless, like his predecessors (see *Tadhkira*, pp. 121-3, and *Tuḥfa*, f. 33r-33v) proceeds to list eight different possibilities for the

motion of the ecliptic orb. Although Ṣadr does not state it, evidently he has in mind rotating the ecliptic with points *E* and *W* held fixed. Point *G* of the ecliptic circle moves to any of the eight points G_1 to G_8, as in figure 10 below. Depending on the final position of point *G*, the ecliptic and the equator circles either coincide twice or once, or they do not coincide. And depending on the above coincidence, the ecliptic and the equatorial orbs exchange positions either partially or fully, except in the eighth case, where only the positions of the stars with respect to the equator, and the length of the day change.

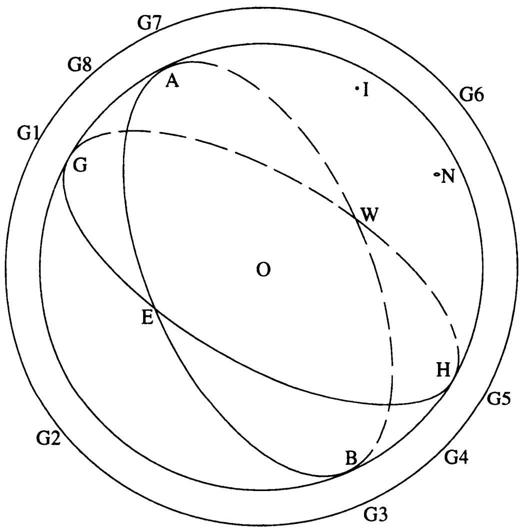


FIGURE 10

Ṣadr rightly maintains that when the ecliptic and equator circles coincide, the day and night are equal, and the seasons of the year cease. The first of these two assertions is true because wherever the sun falls on the ecliptic, it rises and sets along the equator, and hence the day is equal to the night. The second point is also true because for all positions of the sun on the ecliptic circle, it is also on the equator, and therefore there is no variation in the relative position of the sun with respect to the earth for that year; the seasons thus cease.

Ṣadr, however, mentions Shīrāzī's exclusion of the horizon which appears to rotate like a millstone (see *Tuḥfa*, f. 33v). This horizon is defined in

the *Tuḥfa* as the one which coincides with the equator; in other words it is the horizon of an observer located at one of the poles of the universe. Thus when the ecliptic coincides with the equator, both of them coincide with the horizon, and both the day and the night last six continuous months. Yet since the ecliptic is assumed to move in latitude, it eventually departs from the equator, and the sun thus slips above or below the equator (or the horizon). In this latter case, the circle drawn through the sun parallel to the equator does not coincide with it, and the day and night differ again. Shīrāzī mentions that, in this case, the motion of the ecliptic in latitude is one degree per 43 years. Shīrāzī's derivation of this figure is as follows: the inclination of the ecliptic at the time of Ptolemy was found to be 23;51°, whereas at the time of al-Ma'mūn, 690 years later, it was found to be 23;35°. The difference of 16 minutes per 690 years, or 1 minute per 43 years, thus results (for this derivation, see *Nihāya*, f. 30v).

[13] This paragraph, and the following one, deal with the complex and controversial problem of trepidation. Ṣadr's presentation of the theory of trepidation is as concise as that of *Tadhkira* (see *Tadhkira*, p. 125). Ṣadr, however, goes one step farther, and mentions the specific objections which arise against this theory, yet neither of them is as elaborate as Shīrāzī is in the discussion of the above problem (see *Tuḥfa*, f. 34r-37r).

The reasons behind proposing a theory of trepidation, as implied from Ṣadr, are the following:

The second motion of the ecliptic, or the precession of the fixed stars, is known to vary. The value of this precession was determined by Ptolemy to be 1°/100 years, whereas later it was found to be 1°/66 years. Although the second value could be construed as a more accurate measurement, it is also possible to attribute this difference to an actual change in the rate of precession.

The inclination of the ecliptic, as maintained in paragraph 12 above, is also thought to vary.

Finally, some people, whom Shīrāzī claims were influenced by those who practice the art of talismans, maintained that the ecliptic oscillates, in latitude, in a forward and backward motion, along an arc of eight degrees.

Based on the above three propositions, and in what seems to be an attempt to eliminate sudden changes in the ecliptic's direction due to the above mentioned oscillation, it was suggested that all three remarks pertain to one motion, which is caused by one mover. An orb which encompasses the movable ecliptic orb was thus assumed, such that the fixed poles of this orb fall on the circle which passes through the poles of the fixed ecliptic, and are four degrees apart from the poles of the movable ecliptic. If we call this new encompassing orb the ninth sphere, and call the movable one the eighth sphere, then the poles of the eighth sphere are made to move on small circles of eight degrees diameter, whose centers are the poles of the

ninth sphere. This last motion produces a periodic oscillation of the ecliptic, but it also produces a periodic increase and decrease in the inclination of the ecliptic, and a change of the rate of precession (for a clear explanation of the theory of trepidation see Neugebauer, 1962, pp. 290-299).

[14] As mentioned above, Ṭūsī simply dismisses the theory of trepidation without specifying his objections to it, whereas Shīrāzī discusses these objections at length (see *Tuḥfa*, f. 35r-35v, and *Tadhkira*, p. 125). Ṣadr, on the other hand, maintains a middle position; he mentions the objections to this theory without attempting to prove or elaborate on them. His first objection is that the variation in the inclination of the ecliptic is not of the order of 8°/640 years. This objection, as Shīrāzī rightly notices, would not hold if the relevant parameters are adjusted to conform with observation, that is, if instead of 8°/640 years, a more accurate figure which corresponds to the observed variation of the inclination of the ecliptic were used. The more basic objection, however, is that the path traced by every point on the ecliptic as a result of trepidation, is not a small circle which is equal to the circle described by the poles of this ecliptic, rather it is a circle parallel to the cincture of the mover. It is, however, not clear what Ṣadr means by this last statement. If he means that the resulting path is a circle which is parallel to the small circle traced by the pole of the ecliptic, rather than being equal to it, then he is obviously wrong. If, on the other hand, Ṣadr means that the resulting path is the mixed effect of the two circular motions, namely that of the eighth sphere and the small sphere on which the poles of the ecliptic rotate, then he would have understood the argument given in the *Tuḥfa* correctly, but failed to account for the hippopede path, as anticipated in the *Tuḥfa* (see *Tuḥfa*, f. 35r). If, finally, Ṣadr meant that the path which is traced by every point of the ecliptic is not a circular but oval one, then this would be in contradiction with Shīrāzī, who dismisses what he calls the *ihlīlijī* shape as being imaginary (see *Tuḥfa*, f. 35v).

This last point might pertain to the discussion by Ragep of the origins of the theory of trepidation. Ragep maintains that there are two versions of this theory, one depending on a simple schematic model, and the other being a rather more developed version. Ragep further maintains that Ṭūsī was familiar only with the simpler version, and that the developed version, referred to as the motion of the eighth sphere model, was wrongly attributed to Thābit ibn Qurra, and should instead be associated with a later Spanish tradition (for the discussion by Ragep see *Tadhkira*, pp. 400-8). If, however, it is accepted that Shīrāzī actually made reference to both models, as might be implied from the preceding paragraph, then the origin of the theory of trepidation, as discussed by Ṣadr and his predecessors, would be the motion of the eighth sphere model. Incidentally, the attribution of the above mentioned Arabic text to some Spanish astronomer by Ragep is now contradicted by the recent publication of Regis Morelon, who affirms that

Thābit's treatise "on the motion of the eighth sphere" was indeed either the work of Thābit himself, or of one or more researchers of the Banū Mūsā group, under whose patronage Thābit used to work (see Morelon, pp. XLVI-LIII; also for further discussion of the origins of the theory of trepidation, and its description see Dreyer, pp. 203-206, 250-251, 276-279, and Bitrūjī, pp.264-99).

CHAPTER 4

[1] This chapter in Ṣadr's work corresponds to, though significantly different from Book III of Ptolemy's *Almagest* (see *Almagest*, III, pp. 131-172). The major difference between the two works is that the latter involves a detailed examination of observational data, from which Ptolemy tries to derive the optimal model that would represent the motion of the sun, and from which he also calculates the parameters of this model. Ṣadr, like Ṭūsī and Shīrāzī, takes these derivations for granted, and is satisfied with the presentation of the end results of the possible models that may describe the motion of the sun. There are, however, some differences between Ṭūsī, Shīrāzī, and Ṣadr. One such difference is that the *Tuḥfa* and the *Tadhkira* each add a chapter dealing with the models that describe these apparent irregular motions (see *Tadhkira*, pp. 131-43, and *Tuḥfa*, f. 50v-70r). In these chapters the equivalence of the eccentric and epicyclic models is discussed in some detail (on the equivalence of eccentric and epicyclic motion according to Apollonius, see Neugebauer, 1983), whereas Ṣadr simply takes this equivalence for granted. Another difference is in the titles of the chapters; while Ṣadr simply uses the title "on the orbs of the sun", both of his predecessors use "on the orbs and motions of the sun" for their corresponding chapters (see *Tadhkira*, vi, p. 83, and *Tuḥfa*, f. 70r). This last difference, however, has little implication on the similarity between the contents of the three works (for a detailed comparison of the three relevant chapters, see infra).

Of the two fixed parameters which Ptolemy computes for his eccentric model (see *Almagest*, III, pp. 153-69), Ṣadr mentions only one, namely the value of the eccentricity (see infra), whereas he does not mention the longitude of the solar apogee for his epoch. It should be noted that both Ṭūsī and Shīrāzī make reference to this parameter (see *Tadhkira*, p. 147, and *Tuḥfa*, f. 73v-74r).

[2] Ṣadr starts this chapter by noting that the speed of the sun varies according to its position on the ecliptic. This observation is deduced from the unequal lengths of the four seasons (see for example, Pedersen, p. 133). Ṣadr adds to this the observation regarding the variation of the duration of eclipses, in which the sun is found to be a little smaller at the middle of the period of slow motion than at the middle of the period of fast motion.

In his commentary on this section, Ṣadr adds that the variation in the apparent size of the sun can also be deduced from the phenomenon of annular eclipses. When the apparent size of the moon is the same--as in the case when the moon is at its farthest distance from the earth--then an eclipse of the sun at the middle of the period of slow motion is a total eclipse, whereas

an eclipse at the middle of the period of fast motion is an annular one. Therefore, the sun has a smaller apparent diameter during the period of slow motion, and hence is farther away from the earth, and the reverse holds at the middle of the period of fast motion (see *A*, f. 12v).

The corresponding section in the *Tadhkira* simply states the above observation without supplying further evidence, whereas the section in the *Tuḥfa* includes reference to annular eclipses, with the further remark that this evidence is used only by the modern scholars, not the ancient ones, that is, Ptolemy (see *Tadhkira*, p. 145, and *Tuḥfa*, f. 70r-70v). Close examination of Ptolemy's *Almagest* seem to confirm that he was "unaware of the existence of such eclipses of which no records seem to have been made in antiquity" (see Pedersen, p. 208).

[3] After noting that the distance of the sun from the earth varies, Ṣadr, like his predecessors (see *Tadhkira*, pp. 131-5, 145, *Tuḥfa*, f. 50v-54v, 71r, and *Almagest*, III, 3), proposes two models that would account for this variation. The first of these models is the epicyclic one (see figures 11 and 12). In figure 11, the outer and inner circles rotating around center *G*, are the outer and inner surfaces of a solid body called the deferent. Point *G* is the center of the earth. An epicycle which does not encompass the earth is embedded in this solid, such that it is tangent to its two surfaces, and it rotates at the same uniform speed as that of the deferent, but in the opposite direction. The two solids thus complete one revolution at the same time. The sun is carried on the circumference of the epicycle, and its initial position is point *A*. The center *O* of the epicycle rotates in the direction of the sequence of the signs, on an imaginary circle of center *G*, which is located half way between the inner and outer surfaces of the deferent. The circle in figure 12 whose center is *G* is this imaginary circle, and the center of the epicycle rotates on its circumference. As circle *G* rotates through any angle, the epicycle rotates through an equal angle, but in the opposite direction, and the new position of point *A* on the epicycle determines the position of the sun. The maximum distance between the earth, which is located at point *G*, and the sun, is at the beginning of the revolution of the deferent, namely the distance *GA*. The minimum distance *GA″* is reached when the deferent rotates through 180°, and carries point *A* to point *A″*. The first position corresponds to the apogee, whereas the second position corresponds to the perigee. The distance between the earth and the sun thus fluctuates between these two limits, and the above model accounts for the variation of the distance and size of the sun.

[4] The second model proposed is the eccentric model (see figures 13, 14 and 15). In figure 13, the solid bound by the innermost and the outermost circles centered at *G* is the parecliptic orb. The plane of the cincture of this orb coincides with the plane of the cincture of the ecliptic orb. Moreover, the parecliptic orb simulates the ecliptic orb and is concentric with it. The

sun in this model is embedded in the eccentric orb centered around D, which is in turn embedded in the pareclipitic orb. The eccentric orb is bound by two surfaces; its inner surface is tangent to the inner surface of the pareclipitic orb at a point P which is called the perigee, and the outer surfaces of the two orbs are tangent at a point A which is called the apogee.

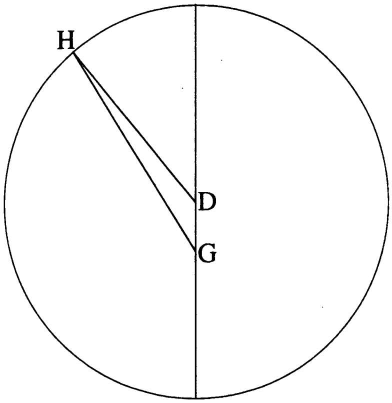


FIGURE 15

Ṣadr rightly notes in this paragraph that the above size of the parecliptic is the minimum required for a representation of the eccentric model configuration, although it may be assumed to have a greater size. The above is true because the parecliptic is not physically equivalent to the ecliptic, and as such it can have any dimension relevant to it. Similarly, the deferent carrying the epicycle can extend beyond the proposed limits (limited only by the lower spheres of Mars), since there is no real physical body to whose dimensions it has to correspond. In both cases, however, the deferent and the parecliptic cannot have smaller sizes than those proposed, if the models were to properly represent the motion of the sun.

If, in figure 13, we trace the path of the center of the sun, then it would be an imaginary circle having a center D and a radius equal to DH. This same circle is drawn in figures 14 and 15. The circle in figure 14 which is drawn around center G tangent to circle D at point A, is an imaginary circle generated from the movement of the point A of the parecliptic orb as a result of the rotation of this orb itself.

[5] In figure 13, the eccentric orb marks two solids in the parecliptic. The first solid falls inside the eccentric orb between the inner surfaces of the eccentric and parecliptic orbs, and it is called the encompassed complementary solid. The second solid encompasses the eccentric orb, and is thus called the encompassing complementary solid. This second solid is bound

by the outer surfaces of the eccentric and parecliptic orbs, and, in contrast to the encompassed one, is thinnest at the point of the apogee, and thickest at the point of the perigee. (See also the corresponding sections in *Tadhkira*, pp. 145-7, and *Tuḥfa*, f. 73r).

[6] The reference in this paragraph is to both the *Tadhkira* and the *Tuḥfa*, where it is stated that Ptolemy chose the eccentric model for its simplicity (see *Tadhkira*, pp. 135, 145, and *Tuḥfa*, f. 71v), and that the motion according to the eccentric hypothesis requires only one circle, whereas according to the epicyclic hypothesis it requires two circles (see *Tadhkira*, p. 135, and *Tuḥfa*, f. 50v-51r, 54v).

Ṣadr, however, objects to the above on the grounds that it is only true if one restricts oneself to plane circles (figures 12, 14 and 15), whereas it is not true if one uses solid orb representations (figures 11 and 13). Ṣadr adds that in the latter case the epicyclic model requires two solids, namely the deferent orb and the epicyclic orb (see figure 11), whereas in the eccentric model three solids are required, namely the encompassing complementary solid, the eccentric orb, and the encompassed complementary solid. Thus, according to Ṣadr, Ptolemy only chose the eccentric model because he wanted to confine himself to plane representations, in which case such a model would indeed be simpler.

[7] In figure 14, arc OA is the longitude of the apogee, arc AH is the (mean) center, and arc LAH is the mean (longitude) which is equal to the sum of the two arcs LA and LH, which is also equal to OAK on the parecliptic. Moreover, arc OT is the true position, and arc TZ (= arc OAK - arc OAT) is the equation, which is equal to OK - OT. If point H is the position of the center of the sun, then the line drawn from the center of the universe, namely point G, to point H intersects the parecliptic circle at point T. Similarly, the line drawn from the center of the eccentric, namely point D, to point H intersects the parecliptic at point Z. The two sides of the angle THZ, namely lines HT and HZ, thus mark the equation arc on the circle with center H. Finally, arc OT is less than arc OK when the sun is descending from the apogee A to the perigee P, and greater when it is ascending. (This paragraph corresponds to *Tadhkira*, p. 149, and *Tuḥfa*, f. 74r-74v).

The mean motion of the center of the sun along the eccentric circle is taken by Ṣadr to be 0;59,8,20°. Whereas the corresponding chapter in the *Tadhkira* does not specify this value, the *Tuḥfa* states that it is approximately 0;59,8° (see *Tuḥfa*, f. 71r), which is itself the truncated value of the one given by Ptolemy (see *Almagest*, III, p. 140).

[8] The equation angle changes from zero degrees at the apogee, through a maximum value, and back to zero degrees at the perigee. The maximum value of this equation is a function of the eccentricity. Moreover, Ṣadr maintains that, if the radius of the eccentric circle was taken to be 60 parts, then the value of the eccentricity according to Ptolemy is 2;30 parts, thus

producing a maximum equation $e_{max} = \sin^{-1}(2;30/60) = 2;20,24°$, whereas according to the modern astronomers it is 2;5 parts, producing a maximum equation $e_{max} = \sin^{-1}(2;5/60) = 1;59,24°$. These two figures are also given in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, p. 147, and *Tuḥfa*, f. 73r). It seems, however, that Ṣadr, like Shīrāzī, wants to point out that the maximum value of the equation is not equal to the eccentricity, as Ṭūsī seems to be saying, but rather is of a similar numerical magnitude determined by the value of the eccentricity.

It should be noted that Ṣadr gives no value for the longitude of the apogee for his own time, as his two predecessors have done (see *Tadhkira*, p. 147, and *Tuḥfa*, f. 73v-74r);

[9] The implicit assumption in this paragraph is that the eccentric and the epicyclic models are equivalent. Following Apollonius, Ptolemy proves the equivalence of these two models (see *Almagest*, III, pp. 148-150), in which the radius of the epicycle is assumed to be equal to the eccentricity (for a modern exposition of this theorem see HAMA, pp. 56-57).

[10] The objection raised in this paragraph, and the response to it in the coming one, have parallels in the *Tuḥfa* but not in the *Tadhkira* (see *Tuḥfa*, f. 74v-75r). The objection simply states that if the eccentric moves the center of the sun through an arc *AH*, such that this arc marks an angle *ADH* at point *D*, and if an angle *AGK*, which is equal to angle *ADH*, is drawn at point *G*, then arc *AT*, which is the distance between the apogee and the apparent position of the sun, is obtained by subtracting arc *KT* rather than arc *ZT* from arc *AK*.

[11] Ṣadr rightly notes in this and in the following two paragraphs that the above objection does not hold. To prove this, Ṣadr presents a two-step argument which he starts by reminding the reader that the objective of astronomy is to locate the apparent position of the sun with respect to an observer on the earth. If the earth is located at point *G*, and if point *H* is the mean position of the center of the sun on the eccentric circle, then the above apparent position, according to Ṣadr, is measured against the parecliptic, and is marked by the point *T* in figure 14, which is the intersection between line *GH* and the parecliptic circle. On the other hand, the mean position of the sun on the parecliptic is marked by point *Z*, which is the intersection between line *DH* and the same circle. Thus, the arc *AT*, which determines the apparent position of the sun, is obtained by subtracting arc *TZ* from arc *AZ*, all three arcs being measured on the circumference of the same parecliptic.

[12] Ṣadr goes on to say that the apparent position of the sun, as derived in the above astronomical model, may indeed correspond to the values listed in the astronomical tables.

Ṣadr does not verify the above; the following, however, seems to be a plausible explanation of what he meant in this statement: in figure 14, line *DG* is of a considerable size relative to the radius of either the eccentric or

the parecliptic circles. Therefore, if a line *GK* is drawn parallel to line *DHZ*, then the arc *AK* will be equal to the mean center.

[14] The diagrams referred to in this paragraph are respectively figures 11, 13, and 16.

CHAPTER 5

[2] The present chapter begins with a summary of the method presented in the *Almagest* for the construction of a lunar theory (For the corresponding sections see *Almagest*, Books IV, V, pp. 173-216). By doing so, Ṣadr follows the example of his predecessors, namely Ṭūsī and Shīrāzī, who restrict their presentations of the Ptolemaic model to the general considerations and features of this model, and then they proceed to point out problems inherent in it, and to suggest solutions to these problems.

The circular path of a planet along the sphere that carries it is called an orb. The first feature to be observed in the lunar model--although having little effect on its actual configuration--is that the path of the moon does not coincide with the path of the sun, i.e., the ecliptic. The two paths, rather, intersect at two points called nodes, which in turn slide along the ecliptic at the rate of three minutes of arc per day, in a direction opposite to the sequence of the signs. This motion is deduced from the shift in the locations of lunar eclipses. The eclipses of the moon, it should be added, are the only observations which are not affected by parallax, and as such they are the most reliable observations for the construction of the lunar model (see Pedersen, p. 161).

The corresponding introductory sections in the *Tadhkira* and the *Tuḥfa* are more elaborate (see *Tadhkira*, pp. 149-53, and *Tuḥfa*, f. 78r, 81r), although the same information in the later sections of these two works are repeated later on in the present one.

[3] A parecliptic orb which moves in a direction opposite to the sequence of the signs at the rate of three minutes per day is thus needed. This is the *jawzahr* orb, or the orb of the two nodes, namely the head and the tail (For the corresponding sections see *Tadhkira* , p. 151, and *Tuḥfa* , f. 80r, 81r).

[4] The second orb posited in Ṣadr's presentation of the Ptolemaic lunar model is the inclined orb, which is so called because it is inclined with respect to the first orb, i.e., the parecliptic, at an angle of about five degrees, which is the maximum latitude of the moon. The two orbs are concentric with the earth, and they both rotate in the same direction, the rotation of the inclined orb, which is also called the motion of the lunar apogee, being 11;9,18° per day. The corresponding values given by Ṭūsī and Shīrāzī are rounded to 11;9° per day (see *Tadhkira*, pp. 151-3, and *Tuḥfa* , f. 80r, 81v-82r).

[5] Two more orbs, namely an eccentric and an epicycle, are posited in this paragraph, in conformance with the Ptolemaic model and with Ṭūsī's and Shīrāzī's expositions of this model (see *Tadhkira*, pp. 149-51, and *Tuḥfa*, f. 80v, 84v). The eccentric orb is deduced from the observation that

the moon's maximum distance from the earth, and its slowest motion, occur at conjunctions and oppositions, indicating that the apogee of the moon is at those positions. Moreover, the maximum speed and minimum distance of the moon from the earth is at quadratures from the sun, indicating that the perigee of the moon is at those positions. An eccentric orb may be applied to produce the above configuration.

A simple eccentric orb similar to that used for the sun, however, does not suffice to account for the observations, and a mobile eccentric orb has to be used instead.

The epicycle is required because of the fact that an additional equation (*ta'dīl*) is needed to locate the position of the moon with respect to the ecliptic.

[6] According to this model, the center of the epicycle and the apogee coincide initially with the mean position of the sun. The inclined orb then moves the apogee in the direction opposite to the sequence of the signs (hereafter clockwise) at the rate of 11;12,18° per day, while the eccentric orb moves the center of the epicycle counterclockwise, such that the mean sun always falls halfway between the two points. But we know that the sun moves counterclockwise at the rate of 0;59,8° per day approximately. Therefore, the apogee moves with respect to the sun at the rate of about 12;11,26° per day in a clockwise direction. The resulting motion of the center of the epicycle away from the sun is thus the same as that of the apogee, but in the opposite direction. Furthermore, the center of the epicycle moves counterclockwise away from the apogee at twice the rate of the motion of either one of them away from the sun, i.e., at the rate of 24;22,52° per day.

The motion of the center of the epicycle with respect to a fixed point on the ecliptic is the motion of this center with respect to the apogee (24;22,52) minus the motion of the apogee with respect to this same fixed point (11;12,18). This motion is called the mean, and is 13;10,34° per day.

[7] Had the eccentric orb been sufficient, then the same pattern of motion would have been repeated in every rotation, and the same speeds would have been reproduced at exactly the same intervals. This, however, does not agree with observations. Thus, if the speed of the moon is recorded at any point A, then the moon would return to the same speed after more than one revolution, i.e., past A. An epicycle was therefore introduced, such that the combined motion of the eccentric and the epicycle would account for this variation.

The corresponding sections in the *Tuḥfa* and the *Tadhkira* are equally descriptive, and the three sections bear much resemblance to each other (see *Tadhkira*, p. 149, and *Tuḥfa*, f. 78v).

[8] When the moon appears smaller in size, it is further away from the observer, i.e., it is in the upper part of the epicycle. Now, since this smaller

size is observed in conjunction with slower motion, the motion of the upper part of the epicycle is opposite to that of the eccentric, so that the net effect is a reduction in the apparent angular velocity of the moon. Similarly, the moon appears to move faster in the lower part of the epicycle, where the two movements add up.

The above is noted during solar eclipses, but also at conjunctions and quadratures, indicating that the slowness of the moon, which is observed while the moon is in the upper half of the epicycle, occurs while the center of the epicycle moves closer or further away from the earth, when this center travels along the eccentric orb. The same applies during the period of fast motion.

The direction of rotation of the epicycle is also deduced from the observation that the period of fast motion of the moon is shorter than the period of slow motion. This means that the arc of the epicycle along which the motions of the epicycle and the eccentric add up is smaller than the arc along which these motions are opposite in direction. Now, since the tangents drawn from the center of the earth to the epicycle subtend a smaller arc on the lower part of the epicycle, i.e., the part which is closer to the earth, this is the part where the faster motions of the moon occur.

Finally, the rounded number 13;4° is given for the daily anomalistic motion of the epicycle, which is the same figure given by Ṭūsī and Shīrāzī (For these numbers see *Tadhkira*, p. 155, and *Tuḥfa*, f. 84v. For the equivalent sections see *Tadhkira*, pp. 149-51, and *Tuḥfa*, f. 84v).

[9] Figures 17 and 18 are two alternative ways of representing the above model: the first is a representation using solid spheres, while the second employs simple circles. The outermost disk in figure 17 is the pareclíptic orb which is moved by the orb of the nodes at the rate of 3 minutes per day in a clockwise direction around point O, which is the center of the earth. The inclined orb is concentric with the parecliptic and it moves the apogee of the eccentric orb clockwise at the rate of 11;12,18° per day. Below it is the eccentric orb in which an epicycle is embedded. The eccentric orb moves in a counterclockwise direction. The center C of the epicycle has a uniform angular motion around center O rather than the center F of its own deferent.

In figure 18, the outermost circle is the cincture of the inclined orb. It moves at the rate of 11;12,18° per day in a clockwise direction around center O. Point A is in the direction of the mean sun, and point A' is the apogee of the eccentric orb for a given configuration. The circle with center F and radius FC is the cincture of the eccentric orb, which moves in a counterclockwise direction at a uniform rate of 12;11,26° per day away from the mean sun, such that this motion is measured around point O rather than point F. The center F of the eccentric moves in a clockwise direction on the

circle with center O and radius OF, at the rate of 12;11,26° per day, which is also measured from the mean sun.

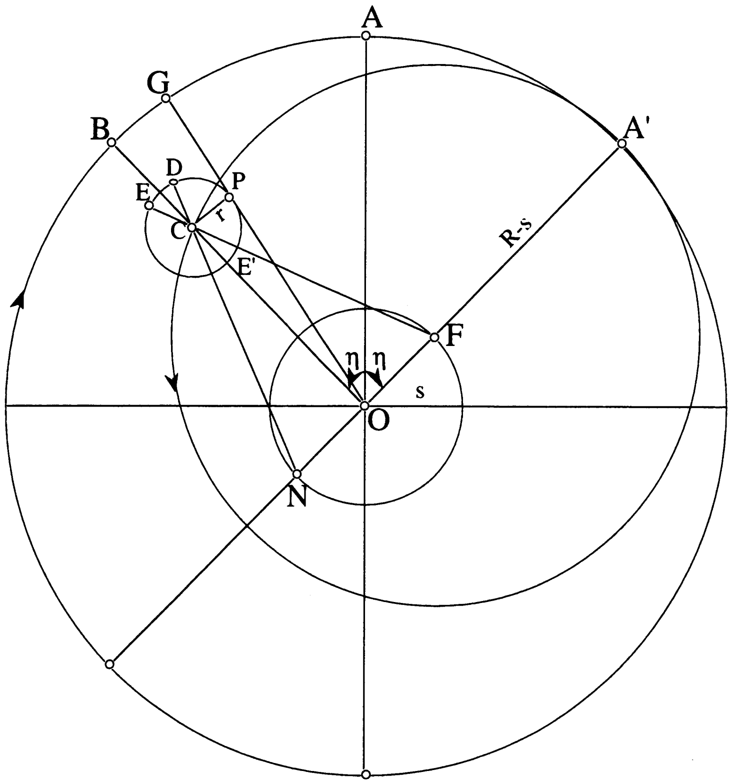


FIGURE 18

If in figure 18 we join points O and C, and let the extension of line OC intersect the cincture of the inclined orb at point B, and if we join OP, such that it is tangent to the epicycle at point P, and let its extension intersect the same circle at point G, then arc BG is called the second equation (the singular "*mufrad*" equation in the *Tadhkira*; see *Tadhkira*, p. 157). It is obvious from figure 18 that when the moon is either at its epicyclic apogee or perigee, i.e., either point E or E', then the lines OC and OP will coincide, and arc BG will be zero.

Now, when the center of the epicycle coincides with the mean sun, i.e., when points A, A', and C coincide, then the maximum value of the arc BG will occur when line OP is tangent to the epicycle. In this case (see figure 19) the sine of arc BG will be $CP/OC = r/OA = r/R$, where r is the radius of the epicycle and is taken as 5;15 parts of the same units in which $R = 60$.

Therefore, at the farthest distance of the epicyclic center, i.e., when the eccentric apogee is in the same direction as the mean sun, the maximum value of the second equation will be: arcsin 5;15/60 = 5;1°, which is one minute in excess of the value given by Ṣadr. It is clear from figure 18 that as long as the moon is descending from point *E* to point *E′* the direction of arc *BG* will be opposite to that of arc *AB*. Therefore, the second equation is subtracted from the mean arc during descent, and the two arcs are additive during ascent (For the corresponding sections see *Tadhkira*, p. 157, and *Tuḥfa*, f. 87r).

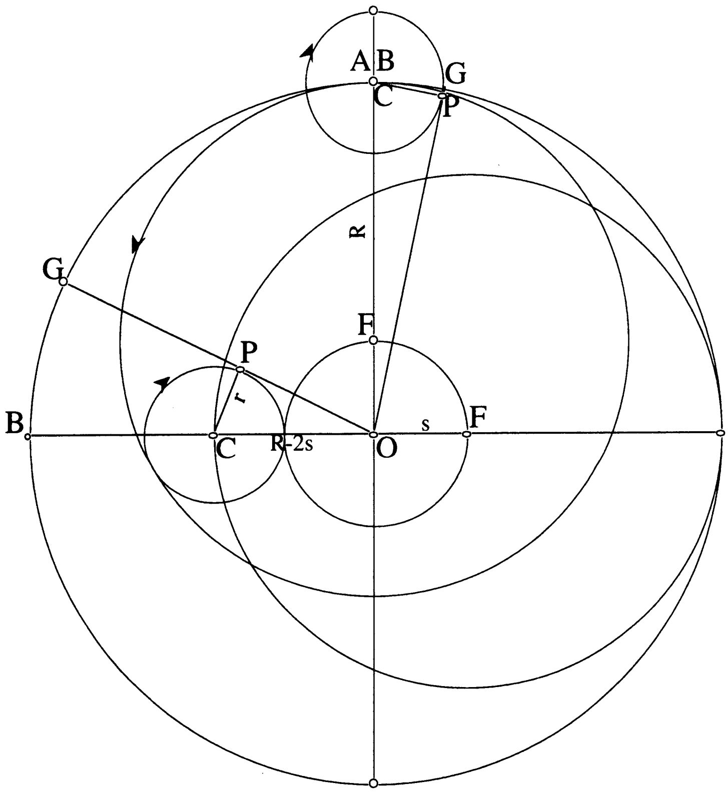


FIGURE 19

[10] The deferent perigee in this model is at the two mean quadratures. The apparent radius of the epicycle at the perigee is thus the greatest angle under which the radius of the epicycle could be seen. Therefore, the maximum second equation is observed at the quadratures between the line *OC* and the line *OP* drawn tangent to the epicycle (see figure 19). This angle,

according to Ṣadr and his predecessors, was found to be 2;40° greater than the maximum angle recorded at the apogee, i.e., 7;40°. If we assume that $OF = s$, then from figure 19 sin $COP = r/OC = 5;15 \div (60\text{-}2s)$. Thus, if we substitute 7;40° for angle COP, s will be 10;19,30 parts, which is rounded to 10;19 (see below, paragraph [12]).

The maximum angle through which the radius of the epicycle is seen while the center of the epicycle is at the apogee of the eccentric is found in the previous section to be about 5°. This angle is a function of the angular displacement of the moon on its epicycle, i.e., the motion in anomaly of the moon. Moreover, the maximum angle of 5° at the eccentric apogee increases by 2;40° at the eccentric perigee. Ṣadr thus proposes a direct approximation to find the values of the increments between apogee and perigee which correspond to values of the second equation at the apogee that are less than the maximum of 5°. The value of this increment corresponding to a second equation equal to $x°$ is simply given as x.(2;40/5;0). Thus for x = 3;0°, the increment or variation according to Ṣadr is 1;36°, and the equation at perigee will be 3 + 1;36 = 4;36 (For the corresponding sections see *Tadhkira*, p. 157, and *Tuḥfa*, f. 87r-87v).

[11] The next step is to account for the positions between apogee and perigee. The distance OC at apogee is 60 parts, whereas it is almost 40 parts at perigee. Thus, Ṣadr deduces that if the distance between the earth and the center of the epicycle is reduced by 10 parts, then the variation in the equation will be 10/20, i.e., half the variation between apogee and perigee, which in the example he gives is 0.5 x 1;36 = 0;48°. More generally, for a decrease in the distance between the earth and the center of the epicycle which is equal to y parts, the above variation of x.(2;40/5;0) should be multiplied by $y \div 20$, giving a final increase over the value of the second equation measured at the apogee of ($x.y$.2;40)/(5;0.20;0).

The net result of the above procedure is to introduce an equation which accounts for the variation due to motion in anomaly, and then to find the corresponding increment resulting from motion in longitude.

The tables thus produced are approximations rather than exact values. To illustrate, consider in figure 20 the three positions which are used by Ṣadr in his examples. Consider triangle OCP in position (1). In this triangle angle COP = 3°, OC = 60 parts, and CP = 5;15 parts. Sin $CPO \div CO$ = sin $COP \div CP$, giving angle CPO = 36;44°. Therefore, the exterior angle ECP = 39;44°.

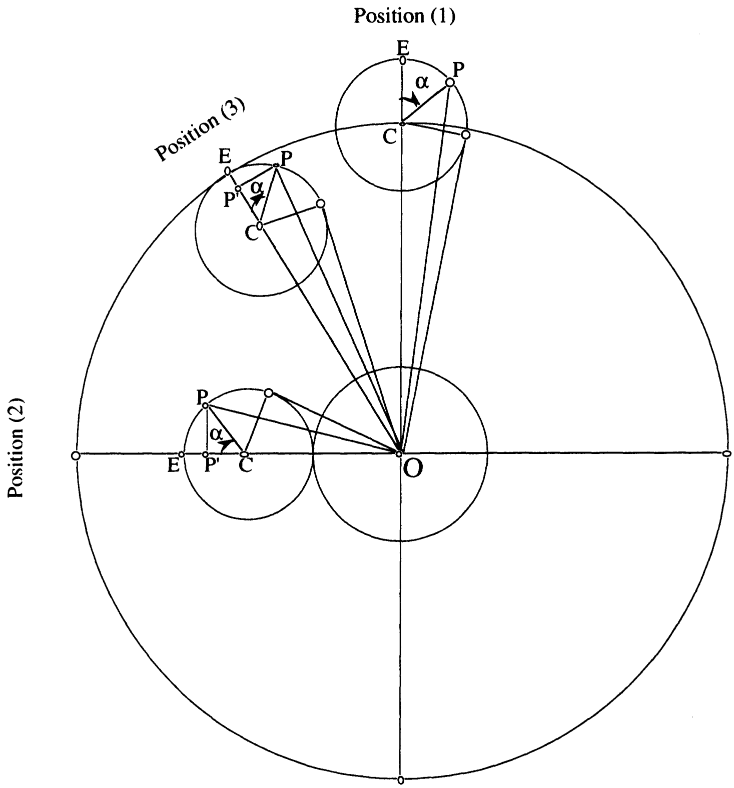


FIGURE 20

Now in position (2) drop the perpendicular *PP'* to *OC*. In triangle *P'PC* angle *C* = 39;44°, and *CP* = 5;15 parts, giving *P'P* = 3;21,21 parts, and *P'C* = 4;2,15 parts. Also we know that in this position *OC* = 39;22 parts, so in triangle *P'PO* tan *P'OP* = *PP'* ÷ (*OC* + *CP'*), giving angle *P'OP* = 4;25°, 11 minutes less than the value obtained by the Ptolemaic approximation used by Ṣadr.

Moreover, in position (3), for a reduction in the length of *OC* equal to half the total reduction between positions (1) and (2), and using the value 20;38 parts for this reduction rather than 20 parts, we get an angle *COP* = 3;34°, 14 minutes less than the value obtained by the above Ptolemaic approximation (For the corresponding sections see *Tadhkira*, p. 157, and *Tuḥfa*, f. 87r-87v).

The example given by Ṣadr is satisfactory in the above special case. In the general case, however, Ṣadr seems to be operating with a modified version of the regular Ptolemaic interpolation function, called by Neugebauer

c_6, which is the fraction by which the equation increment is reduced at points between apogee and perigee.

Ṣadr's procedure implies that his interpolation function c can be defined by the equation:

$$c = \frac{OC_a - OC}{OC_a - OC_p},$$

where OC_a is the distance of the epicyclic center from the center of the world at apogee, and OC_p is the distance at perigee, while OC is the distance at any point in between which can be calculated by the general formula (see figure 18):

$$OC = \sqrt{(R-S)^2 - (s.\sin 2\eta)^2} + s.\cos 2\eta$$

where η is the elongation, R is the radius of the inclined sphere, and s is the eccentricity 10;19 as given by Ptolemy.

Ptolemy's interpolation function, on the other hand, is defined as (see Neugebauer, 1969, pp. 193, 198):

$$c_6 = \frac{\sigma - \sigma_a}{\sigma_p - \sigma_a},$$

where σ is the maximum angle at any point between apogee and perigee, σ_a is the maximum angle at apogee, and σ_p is the maximum angle at perigee, and where in each instance σ is given by the following formula:

$\sigma = \arcsin\ (r/OC)$, where r is the epicyclic radius = 5;15, and OC is the distance of the epicyclic center from the center of the world, determined by the above expression.

Now, since the angles in question are small, we may approximate the angles by their sines, in which case we get the following expression for c_6:

$$c_6 = \frac{r/OC - r/OC_a}{r/OC_p - r/OC_a},,$$ which yields

$$c_6 = \frac{OC_a - OC}{OC_a - OC_p} \times \frac{OC_p}{OC},$$

which is different from Ṣadr's expression by the second term.

This difference is reflected in the graph of both functions around the central part of the graph, and reaches a maximum around $\eta = 45°$. But the

general shape of the graphs of both functions is the same, and the limiting points at apogee and perigee are identical (Incidentally, the same discrepancy is noted between the interpolation function used by Copernicus and that used by Ptolemy, resulting in similar graphs; see graph for c_4 in Swerdlow-Neugebauer, part 2, p. 600, figure 15.) Since, in the first place, the Ptolemaic function is itself an approximation, a slightly modified approximation function did not seem to bother Ṣadr.

[12] The resulting variation calculated above is the angle at which the radius *CD* of the epicycle is seen by an observer located at point *O* (see figure 18). This variation is either added to or subtracted from the mean longitude measured on the cincture of the inclined orb. It is clear from figure 18 that this variation angle is a function of the motion in anomaly around point *C*. This motion, which is tabulated in astronomical tables, has been up to this point measured from point *E*, which is the intersection between *OC* and the epicycle.

Ṣadr notes that measuring the motion in anomaly in the above manner is valid only when the center of the epicycle is at apogee or perigee (For the corresponding sections see *Tadhkira*, p. 157-9, and *Tuḥfa*, f. 88r). At any other position the motion in anomaly is measured from point *D*, which in figure 18 is the intersection between line *NC* and the epicycle. Point *N* is the prosneusis point, and is diametrically opposite to point *F*, which is the center of the eccentric. Thus the angle through which *CP* is seen from point *O* is a function of a corrected value of the motion in anomaly, i.e. one to which angle *ECD* is either added or subtracted. This correction angle is called the first variation because it should be obtained first in order to find the other variations. In other words, the value of the motion in anomaly that should be entered into the tables is not the mean value; rather, it is corrected by adding the variation due to prosneusis (For the sections discussing the first variation see *Tuḥfa*, f. 88r-88v, and *Tadhkira*, pp. 157-9).

The above variation, according to Ṣadr, reaches its maximum when the line *CN* is perpendicular to the apsidal line *NOA'* at point *N*. This situation is similar to Ptolemy's determination of the maximum equation in the chapter on the orb of the sun (For an illustration of the method given by Ptolemy to prove this point see HAMA, part 1, p. 57; also see *Almagest*, Book III, p. 156, and Pedersen, p. 141-143). Ṭūsī and Shīrāzī, however, state that the maximum value of the first equation occurs when "the center of the epicycle is at sextile or trine with respect to the sun" (see *Tadhkira*, p. 156-7, and *Tuḥfa*, f. 88v). The above two statements are not contradictory, since, as Shīrāzī notes, the difference between the two epicyclic apogees, i.e., between the visible and the mean apogees, reaches its maximum value when the line joining the prosneusis point and the center of the epicycle is perpendicular to the line joining the centers, i.e., the center of the earth and

the center of the deferent, and this happens when the center of the epicycle is around sextile or trine with respect to the sun (see *Tuḥfa*, f. 90v).

The radius of the circle around which the center of the eccentric and the prosneusis point rotate is given as the usual 10;19 parts. The "previously mentioned consideration" is simply that the radius of the inclined orb is equal to 60 parts. Moreover, the maximum value of the variation is a function of this radius, as is clear from figure 21; angle *OCN* in this figure is the maximum first equation according to Ṣadr, since in this configuration line *CN* is perpendicular to the apsidal line *NOA'*. Now in triangle *CNF* angle *CNF* = 90°, *CF* = 60 - 10;19 = 49;41 parts, and *NF* = 20;38 parts; therefore, *CN* = 45;12 parts. Thus, in triangle *CNO* the tangent of angle *NCO* = *ON*/*CN*, and the maximum first equation is found by calculation to be 12;51°, whereas table V8 of the *Almagest* has a listed maximum of 13;9° (see *Almagest*, Book V, p. 238). The corresponding mean elongation will then be 180 - (12;51 + 90) = 51;26°.

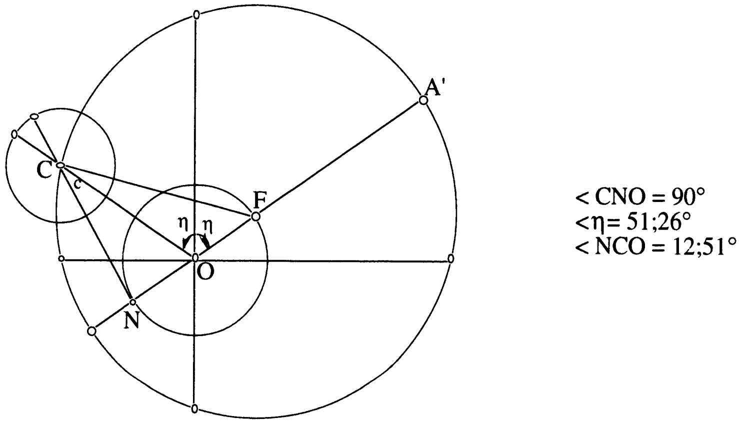
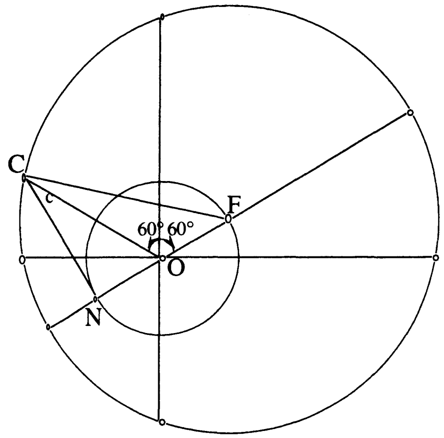


FIGURE 21

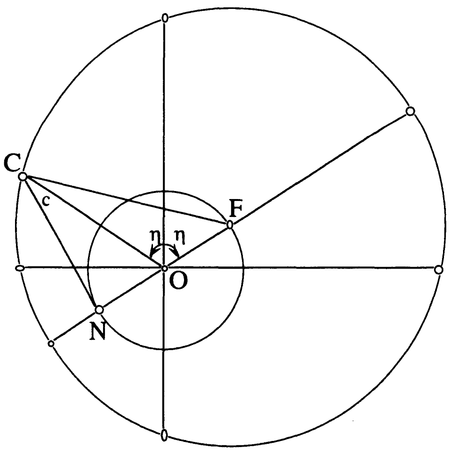
It is clear, therefore, that the maximum value of the first equation occurs when the center of the epicycle is somewhere around trine or sextile with respect to the sun, and not exactly at those points. The equation obtained for a mean elongation of 60° is 13;3°, in which case the angle between the lines *CN* and *NOF* is 106;57° rather than 90° (figure 22).



< η = 60°
< c = 13;3°
< CNO = 106;57°

FIGURE 22

Finally, for the maximum value of the first equation of 13;9°, which is given by Ptolemy, and which corresponds to a mean elongation of 57°, the angle *CNO* will be 100;52° (figure 23).



< 2η = 114°
< c = 13;8°
< CNO = 100;52°

FIGURE 23

[13] This paragraph refers to the fact that for positions of the center of the epicycle which are equidistant from the apogee, the value of the first equation is the same. The difference between the two cases is that the first equation is added to the mean anomaly when the epicycle is descending from the apogee, whereas it is subtracted when the epicycle is ascending (see figure 24).

(For the corresponding sections see *Tadhkira*, pp. 157-9, and *Tuḥfa*, f. 88v)

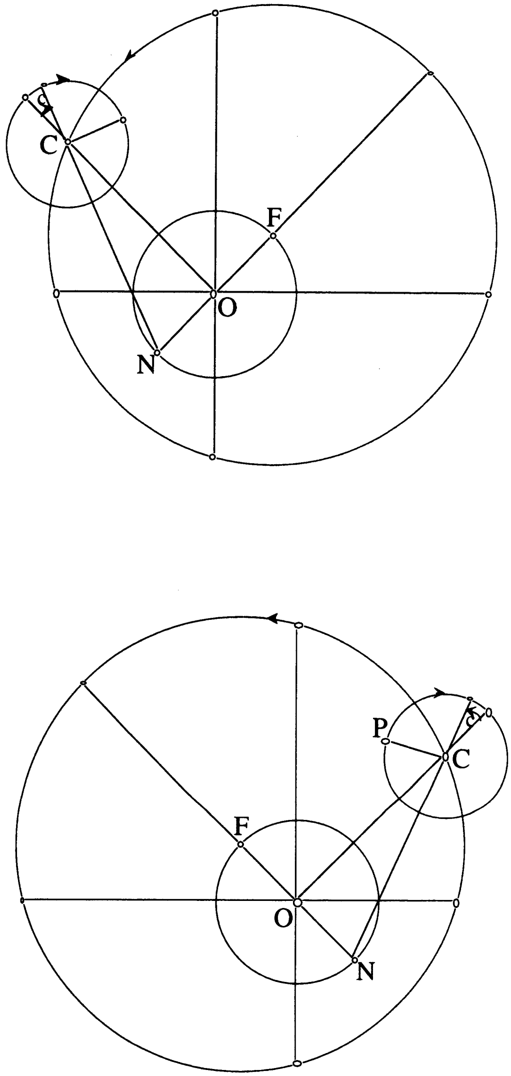


FIGURE 24

[14] This paragraph is hard to understand. What it seems to be saying is that the mean epicyclic apogee oscillates around the true epicyclic apogee, and that the direction of its motion is a function of the position of the center of the epicycle with respect to the mobile eccentric apogee, on the one

hand, and with respect to the line drawn through the prosneusis point perpendicular to the apsidal line of the eccentric, on the other. This last line is not specified in the text, but it is clearly defined in the commentary that follows it (see MS *A*, f. 21v).

The line drawn through the prosneusis point perpendicular to the apsidal line of the eccentric is, as shown in paragraph [12] above, the line around which the maximum value of the first equation is obtained. In other words, the first equation increases in value from zero when the mean moon is at apogee or perigee, to a maximum around sextile or trine, then it decreases to zero at the next perigee or apogee, and so on. Moreover, this means that the mean epicyclic apogee will start separating from the true (visible) epicyclic apogee as the center of the epicycle starts to move away from the eccentric apogee, until it reaches a maximum at sextile; then the mean apogee will reverse the direction of its motion with respect to the true one until they coincide; then it will cross it and separate from it, while maintaining the same direction of motion, until it reaches a maximum at trine, and so on. Thus we have four positions where the mean epicyclic apogee coincides with the true epicyclic apogee, namely when the center of the epicycle is at eccentric apogee or perigee. Moreover, the first equation will reach a maximum at the four points where the center of the epicycle is around sextile or trine with respect to the sun. At these last four points the mean epicyclic apogee reverses the direction of its motion with respect to the true epicyclic apogee in the manner specified in the text. The motion of the mean epicyclic perigee with respect to the true perigee is obviously opposite to that of the apogees. Figure 25 illustrates the relative positions and the directions of motions in all the above phases.

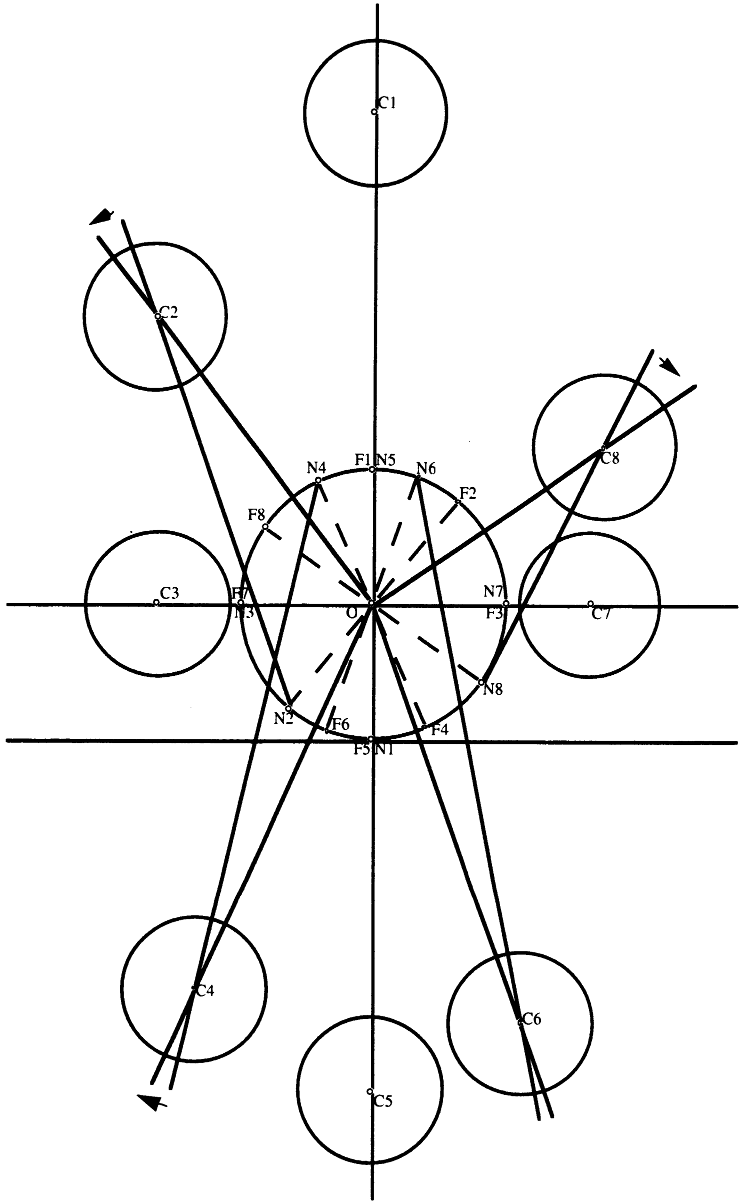


FIGURE 25

The text starts at position 4 in figure 25, where the mean apogee moves from a maximum value back toward the true apogee in a clockwise direction, i.e., opposite the direction of the sequence of the signs, until the two

apogees coincide at position 5. They then start to separate again, with the mean apogee maintaining the same direction of motion with respect to the true one, until they reach a maximum separation around position 6, where their relative direction of motion is again reversed, and so on. The text jumps over this shift in the direction of motion that occurs around position 6, but the general idea may still be discerned (For the corresponding sections see *Tuḥfa*, f. 90v-91v, and *Tadhkira*, p 211).

[15] The problem presented in this paragraph is one which has baffled many medieval Muslim astronomers, and on which an extensive literature was compiled (On objections to Ptolemy's models, and on the attempts to correct them see Saliba, 1981, pp. 75-84, and Saliba, To Appear). Two problems are raised in relation to the model of the moon; the first is the problem of having a body rotate uniformly around one point (the center of the universe), while maintaining a constant distance away from another moving point which is itself the center of the deferent . The second problem is that of measuring the motion in anomaly away from the mean epicyclic apogee which is aligned with the prosneusis point, rather than measuring it from the visible epicyclic apogee. This means that some mechanism is needed to slant the epicyclic diameter passing through the visible apogee, to the new reference position passing through the mean one. In both cases, the problem is to find feasible physical models that would produce these effects without contradicting basic principles, such as the principle that spheres can only rotate uniformly around their own centers (For the corresponding sections see *Tadhkira*, pp. 159-61, and *Tuḥfa*, f. 95r).

[16] This paragraph betrays a mistake in Ṣadr's understanding of Ṭūsī. While Ṣadr correctly states that Ṭūsī posited three additional spheres to account for the uniform motion of the center of the epicycle around a point which is not the center of its path (see *Tadhkira*, p. 205), and while it is correctly stated that Ṭūsī indicates that a maximum discrepancy of one sixth of a degree occurs between his model and that of Ptolemy (see *Tadhkira*, p. 209), Ṣadr, nonetheless, does not seem to understand what this discrepancy refers to. Ṣadr's understanding is that the discrepancy is equivalent to the variation, and he indicates in his following commentary that this is the first equation, and that its maximum value is supposed to occur at sextile and trine (see MS *A*, f. 23r). Ṭūsī, however, is clearly referring to the maximum difference between the hypothetical path of the center of the epicycle in his model and in Ptolemy's, and this difference, as Ṭūsī correctly maintains, occurs at the octants (for an explanation and proof of Ṭūsī's point see Ragep's commentary in *Tadhkira*, pp. 443-5). It should be noted, however, that Ṭūsī is wrongly assuming that the path plotted in Ptolemy's model was verified by observation at all points, and he thus calculates the maximum divergence between his model and that of Ptolemy, as if this were the divergence between the theoretical model and the observation. This is obvi-

ously a false assumption, since there is no evidence that Ptolemy had any observations other than the ones at conjunction, opposition, and the points where the moon is close to either the epicyclic perigee, or the epicyclic apogee (see for example, Pedersen, V, p. 223). ʻUrḍī was fully aware of the above fact when he proposed a model in which he felt free to violate the directions of motions of the different spheres in the Ptolemaic model, and in which the trajectory of the path of the moon in between the four points of observation is different from the Ptolemaic one. In other words, ʻUrḍī tried to duplicate the Ptolemaic model only at those points where Ptolemy actually had conducted some observations, and where eclipses may occur, and departed from it in virtually every other respect (see Saliba, 1989, pp. 157-164).

[17]-[19] These three paragraphs are a description of the so called Ṭūsī couple, which was introduced by Ṭūsī in order to produce rectilinear motion by a combination of uniform circular motions. The three sections are almost identical to the corresponding sections in the *Tadhkira* (see *Tadhkira*, pp. 195-9), and are illustrated in figure 26 (For further discussion of the Ṭūsī couple see for example, HAMA, pp. 1035, 1456).

[20]-[21] The corresponding section in the *Tadhkira* is more elaborate, and its structure is different from the present text (For comparison see *Tadhkira*, pp. 201-5). Shīrāzī, on the other hand, does not mention Ṭūsī's method in the *Tuḥfa*; thus Ṣadr could not have quoted Shīrāzī's rendering of the corresponding section in the *Tadhkira*.

To illustrate this section consider in figure 27 the three outer circles to be concentric around the center O of the universe. The outermost circle is the cincture of the parecliptic, and it moves in a clockwise direction. Next is the cincture of the inclined orb, also moving in a clockwise direction. The innermost of the three circles is the deferent, and it moves in a counterclockwise direction. This deferent has convex and concave surfaces, and hence it has a thickness.

The large circle of the Ṭūsī couple is embedded in the thickness of the deferent, such that the convex surface of the former is tangent to both the convex and the concave surfaces of the latter. The movement of this large circle is in a counterclockwise direction. The small circle of the Ṭūsī couple, on the other hand, is tangent to the large circle, and it moves in a direction opposite to that of the large circle, at twice its speed. Finally, a circle which retains the position of the epicycle, and which keeps it from rotating freely, is tangent to the inner surface of the small circle, and the epicycle falls inside this retainer circle. The motion of the retainer circle, according to Ṭūsī, is similar to that of the large circle, and moves in its direction.

In figure 27 point O is the center of the deferent, point Z the center of the large circle, point H the center of the small circle, and point T the center of the epicycle.

It is clear from figure 27 that the diameter of the small circle of the Ṭūsī couple is equal to the radius of the large circle, plus the radius of the epicycle, plus the thickness of the retainer circle.

Now if we trace the path of the center of the epicycle by the motion of the large circle alone, i.e., without the effect of the motion of the small circle, then we get the circle with center Z and radius ZT as that path; this is now called the cincture of the large circle. Similarly, the path of the center of the epicycle due to the motion of the small circle alone, i.e., without the effect of the motion of the large circle, is the circle with center H and radius HT; this is the cincture of the small circle. It is clear from figure 26 that the diameter of the cincture of the small circle is equal to half the diameter of the cincture of the large circle, and that the actual motion of the center of the epicycle is a result of the combination of its hypothetical motions along these two circles.

Figure 28 illustrates the motion of the center of the epicycle. The center Z of the large circle is moved by the deferent through an angle α, in a counterclockwise direction. Center H of the small circle is also moved through an angle α, in a counterclockwise direction, due to the movement of the large circle. Finally, the center T of the epicycle moves in a clockwise direction, through an angle 2α, due to the movement of the small circle. The small and large circles are the two circles of the Ṭūsī couple, and as a result of their respective motions the center T of the epicycle moves along the line OZT, thus producing a rectilinear motion as a result of the combination of two uniform circular motions. Moreover, the center T moves from a maximum distance away from the center of the universe, where points T and A coincide, to a minimum distance which is equal to the above maximum distance reduced by the diameter of the large circle.

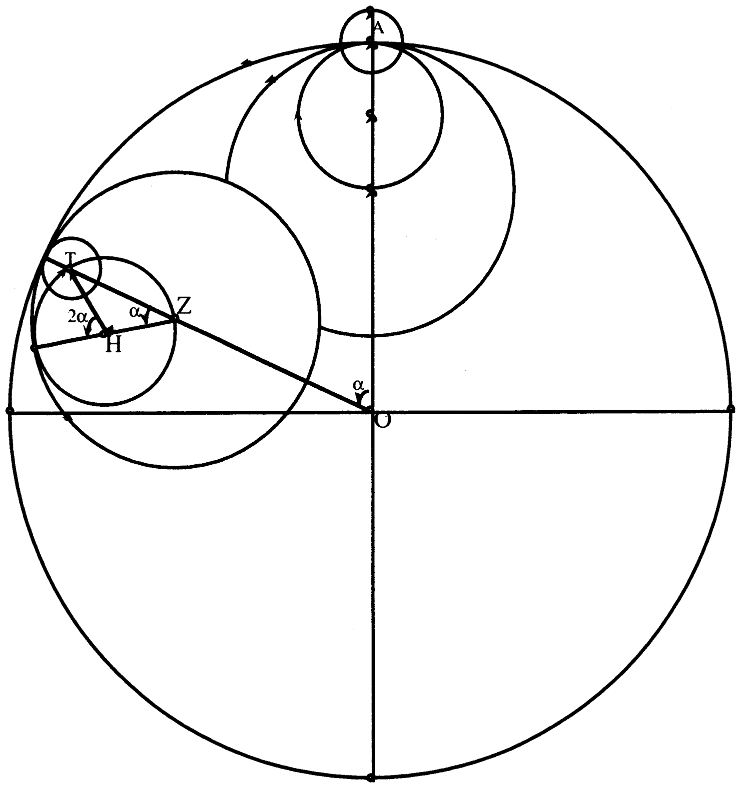


FIGURE 28

The three circles used by Ṭūsī in the above model, namely the large and small circles, and the retainer circle, are the cinctures of the three additional spheres which were introduced in paragraph [16] above, in order to save the theoretical principle that the spheres should rotate uniformly around their centers.

[22]-[25] These paragraphs represent a short summary of Ṭūsī's attempt to solve the problem of the prosneusis point. Here too, the style of Ṣadr differs from that of Ṭūsī, and it is not clear whether the section is his own rephrasing, or whether it is based on some other intermediary source (For the corresponding section see *Tadhkira*, 217-21; also for a discussion of this method see the same source, pp. 448-55).

Ṭūsī, like many astronomers before him, noted that the motion in anomaly was measured on the epicycle from a point which is aligned with the prosneusis point, rather than being measured from the epicyclic apogee, which is aligned with the center of the universe. He thus tried to devise a mechanism through which the displacement of the reference point, from the

visible epicyclic apogee to the mean epicyclic apogee, could be produced as a result of a combination of uniform circular motions of concentric spheres that rotate around their own center (For the earliest use of this method of homocentric spheres by Eudoxus see Neugebauer, 1969, pp. 153-156).

While Ṭūsī introduces his method after discussing what seems to be a similar, but less successful, method proposed by Ibn al-Haytham (see *Tadhkira*, pp. 209-17), Ṣadr proceeds directly to Ṭūsī's alternative mechanism, without going through the elaborate introductory discussion. In short, this mechanism involves the use of three spheres which are concentric with the epicycle. The pole of the innermost sphere coincides with the epicyclic apogee, whereas the pole of the outermost sphere is at a distance from the first pole which is equal to half the maximum variation, i.e., half the maximum value of the first equation, which is the maximum displacement of the mean epicyclic apogee from the true one. Both spheres rotate at a speed equal to that of the deferent, and in the same direction.

The pole of the middle sphere is located halfway between the two spheres mentioned above, and it rotates at twice their speed in the opposite direction. As a result of the rotation of the outermost sphere, the epicyclic apogee will trace a circular path whose center is the pole of the outermost sphere, and whose radius is equal to half the maximum value of the first equation. This path is called the large circle. Moreover, as a result of the rotation of the middle sphere, the epicyclic apogee will trace a circle which is half the size of the large circle produced above (see figure 29). These two circles, according to Ṭūsī and Ṣadr, form a Ṭūsī couple. This couple, however, functions in a way different than the simple plane version proposed above: to start with, the two circles of the couple do not fall in the same plane. Nevertheless, it may be assumed with reasonable accuracy, that the two circles are close enough to approximate a plane couple (For a full discussion of the spherical couple see Saliba and Kennedy), since they both trace small arcs at the periphery of their spheres, such that the planes of the two circles appear to overlap when viewed from the center of the epicycle.

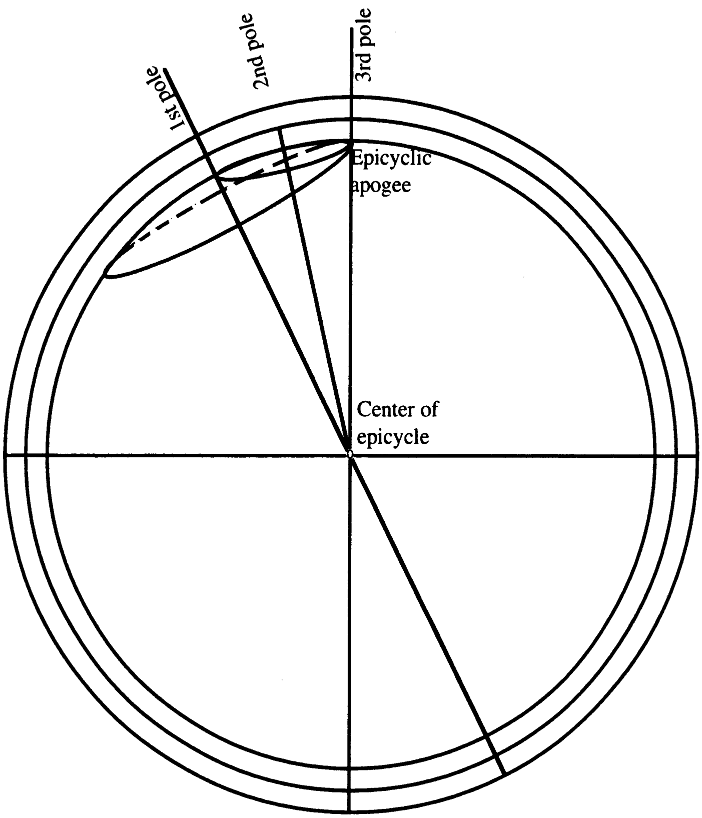


FIGURE 29

The second difference in the use of this couple is that it moves the lower end of the diameter of the small circle, rather than the upper one. To illustrate this point consider figure 29.a. While the above couple is used to move point A along the diameter AE, the present one is used to move point C along diameter DF. It can easily be proved that this result is a corollary of the first condition just stated, and that the two extremities of diameter AC slide along the two perpendicular diameters AE and DF of the large circle.

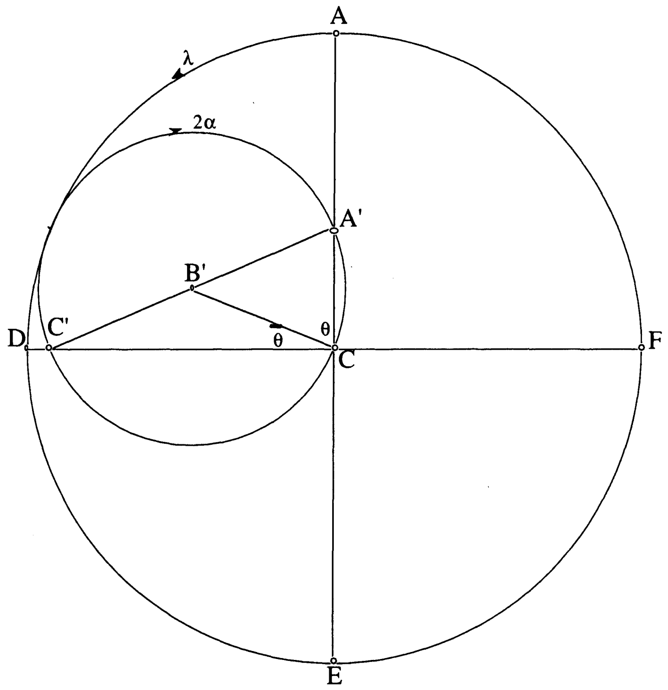


FIGURE 29.a

Now, to illustrate the actual function of the whole apparatus consider figure 29.b: the plane of the Ṭūsī couple is placed such that it is perpendicular to the plane of the epicycle. Moreover, the first of the three spheres rotates counterclockwise at the same speed as the deferent, while the second moves at double that speed, and in the opposite direction. Let point O be the center of the epicycle, and point C the pole of the first and third spheres. Moreover, at the eccentric apogee we let line OC point toward the epicyclic apogee. The pole B of the second sphere is then placed on the line drawn at C perpendicular to the plane of the epicycle, such that distance CB is equal to half the maximum variation of the first equation. If the deferent now moves through 90°, the epicycle moves to the eccentric perigee, where the angle between the true and visible perigees is maximum. As a result of this motion, point C slides to point C', and with it point B moves to B'. The motion of point C' is thus equal to twice the radius CB of the small circle, which is equal to the maximum variation along the plane of the epicycle. The new pole of the first and third spheres is at point C', and the axis of rotation of the third sphere is OC'. Therefore, as a result of the rotation of the third sphere, point B' moves to B'' and A' to A''. This means that all points in

the three spheres now return to their original relative positions, but they are all displaced through a distance equal to the maximum variation.

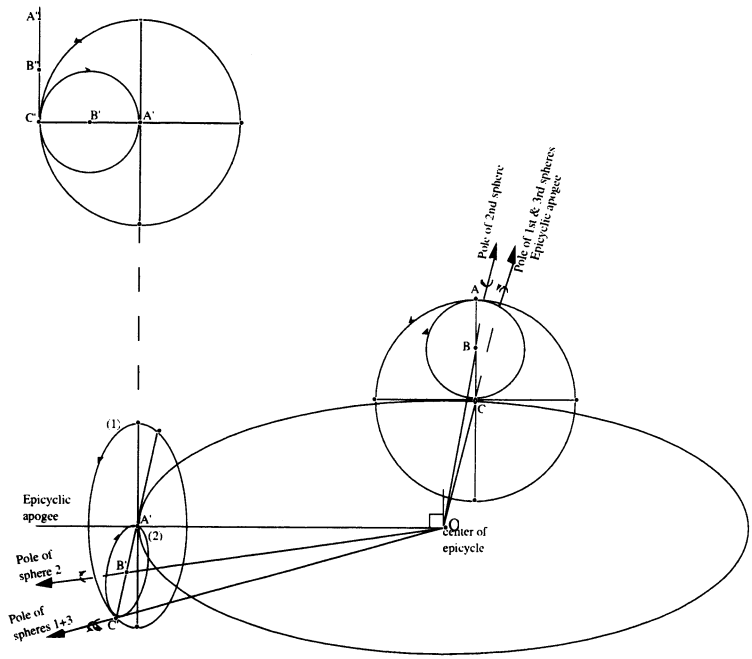


FIGURE 29.b

Now, if the true apogee is fixed along the line OC, and if the mean apogee is carried along line OC', then the mean apogee clearly oscillates on an approximate great circle around the true one, such that it reaches a maximum distance equal to the maximum variation of the first equation at the eccentric perigee, and coincides with it at the eccentric apogee.

The anomalistic motion can now be measured from the mean epicyclic apogee rather than from the true one. Only uniform circular motions are employed, however, and the same effect of a prosneusis point is produced without actually employing this problematic concept.

[26] Ṣadr now goes on to discuss Shīrāzī's solution for the problems of the Ptolemaic model. This solution entails using an eccentric orb whose center is located half way between the center of the universe and the center of the eccentric orb in the previous model. The center of the eccentric is thus 5;10 parts away from the center of the universe. The new eccentric moves at the same speed and in the same direction as the old one. Shīrāzī then introduces two epicycles, both having diameters equal to the value of the Ptolemaic eccentricity, i.e., 10;19 parts. The first epicycle is embedded

in the eccentric orb, both moving at the same speed and in the same direction. The center of the second epicycle is carried on the first one, and it carries the moon. This second epicycle moves opposite to the direction of motion of the first one, and its motion is equal to that of the eccentric plus the motion in anomaly. Figures 30 and 31 are respectively a solid sphere and a simple circle representation of the above model.

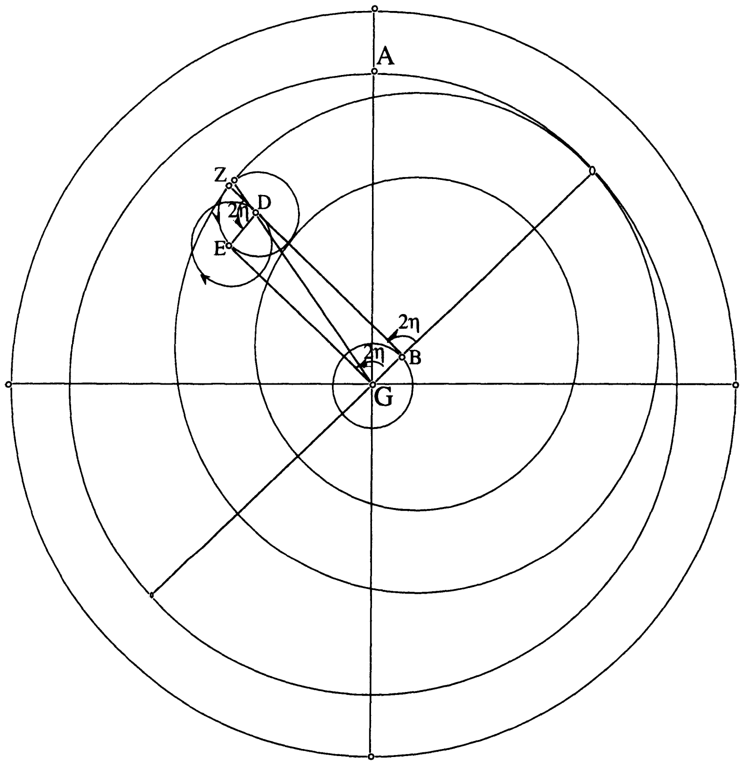


FIGURE 30

In Ṣadr's representation of Shīrāzī's model, he seems to confuse the solid body and plane circular representations of the two epicycles; the diameter of the cincture of the first epicycle, on which the center of the second epicycle travels, is 10;19 parts. As such, the actual diameter of the first epicycle is twice that of the given one, i.e., 20;38 parts, and the convex surface of the second epicycle is thus tangent to the convex surface of the first one (see figure 32).

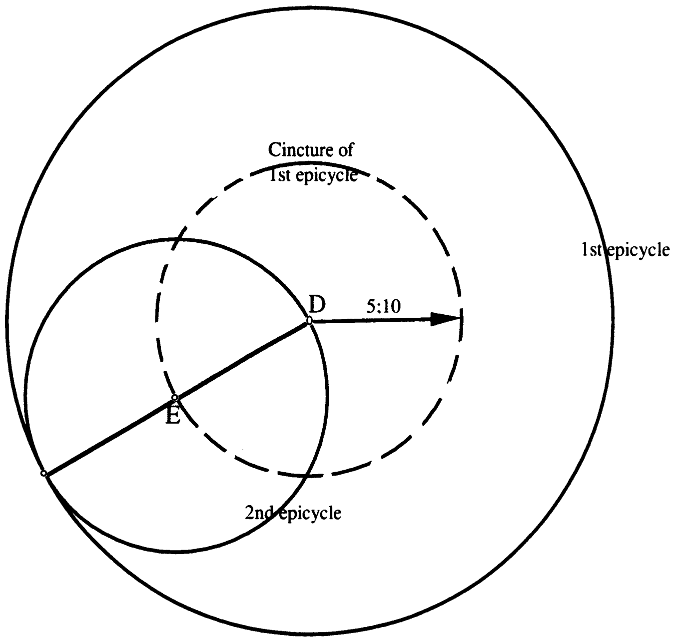


FIGURE 32

It should be noted that the above method, which Ṣadr attributes to Shīrāzī, can be found only in the *Tuḥfa*, while it seems that it was not yet developed at the time of the writing of the *Nihāya*. Moreover, this method is briefly presented in the *Tuḥfa* after an elaborate discussion of a method proposed by a person whom Shīrāzī calls "a distinguished contemporary". This distinguished contemporary, as Saliba has shown, is none other than 'Urḍī, and although Shīrāzī criticizes 'Urḍī's model for the moon, he nonetheless uses the geometric tool commonly referred to as 'Urḍī's lemma as a basis for his own model. Furthermore, most of Shīrāzī's discussion of his own model pertains to the problem of the prosneusis point, and, as Ṣadr rightly notes, it fails to introduce any original solution to this problem (On the contributions of 'Urḍī and his influence on Shīrāzī see Saliba, 1990, and Saliba, 1980; on 'Urḍī's lemma see Saliba, 1981. For a discussion of the lunar models of both Shīrāzī and 'Urḍī see Saliba, To Appear, pp. 49-60; also for 'Urḍī's lunar model see Saliba, 1989. For Shīrāzī's discussion of 'Urḍī, and the presentation of his own model see *Tuḥfa*, f. 97v-98v, and f. 98v-100v).

[27] In figure 31 the circle with center B is the eccentric, and the eccentricity BG is equal to 5;10 parts, which is half the Ptolemaic eccentricity. The first epicycle is the circle with center D, and it rotates at the same speed

and in the same direction as circle *B*. The second epicycle is the circle with center *E*, and it rotates in the direction opposite to the first one.

In this paragraph Ṣadr proves that the lines *BD* and *GE* are parallel, and hence that angles *ABD* and *AGE* are equal. This means that the angle through which the eccentric orb rotates is equal to the angle through which the center of the moon-carrying epicycle rotates. In other words, the rotation of both circles is uniform around their own centers, and as such the principle of uniform circularity is retained.

Ṣadr's proof of the equality of the above angles amounts to the same results reached through the use of 'Urḍī's lemma, although the former's method is obviously cumbersome, whereas the latter's is elegant and concise. It would seem, therefore, that Ṣadr had only recourse at second hand to the work of 'Urḍī through the mediation of Shīrāzī.

[28] The path traced by the center of the epicycle in the above model is the result of combining the motion of the eccentric with the motion of the first epicycle. This resulting path is clearly not circular. This fact, however, is not objectionable, since, according to Ṣadr, what matters is that the line joining the center of the epicycle to the center of the earth rotates at a uniform speed around the center of the earth (angle *AGE* in figure 31), even though the arcs transcribed by the center of the second epicycle--along its own path, and during equal intervals of time--are not equal.

The movement of the center of the eccentric around the center of the earth is also not objectionable, since the distance between them does not vary; and therefore the proof given for the uniformity of motion around the center of the earth still holds.

[29] Whereas Shīrāzī's lunar model resolves the problem of the uniform rotation of circles around their center, Ṣadr rightly notes that the problem of the prosneusis point is not resolved in this model; figure 33 superimposes Shīrāzī's model (continuous lines) over that of Ptolemy (dashes). It is clear from the figure that the new visible epicyclic apogee in Shīrāzī's model is still considerably different from the mean epicyclic apogee of the Ptolemaic model. Ṣadr thus proceeds to present his own lunar model which purports to solve all the above problems.

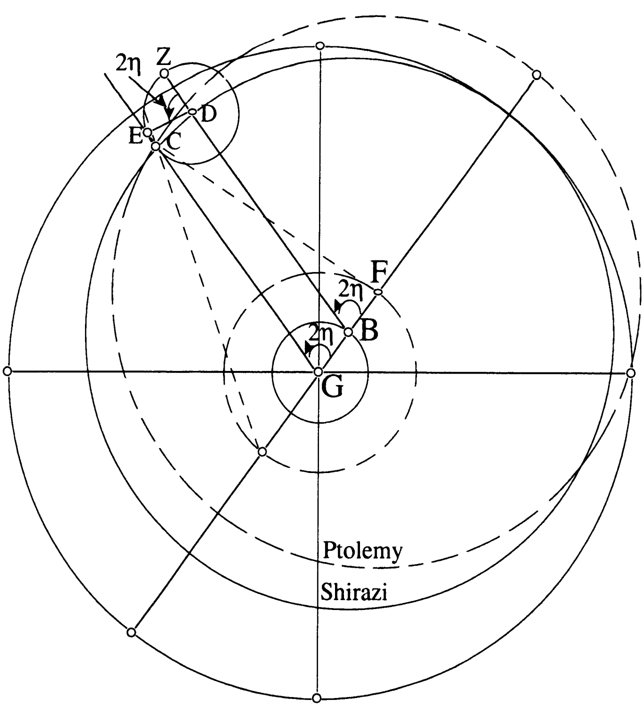


FIGURE 33

[30]-[31] The reference in this paragraph seems to confuse, once more, the solid body and the circular representations. It seems, however, that Ṣadr is thinking of solid bodies only in the first sentence, where he says that the convex surfaces of the second and third epicycles are tangent. After this point, Ṣadr seems to be referring to the circular paths of the centers of each epicycle, and as such the radius of the third small epicycle would be equal to the maximum value of the first variation plus half the size of the moon, rather than the entire size of the moon.

In this paragraph Ṣadr seems to propose a new lunar model of his own, ostensibly attempting to take care of the prosneusis point as well. The text is extremely cryptic, and allows at least two possible interpretations. In the first instance, the model described here could be intended as a modification of Shīrāzī's model, in an attempt to solve the prosneusis problem. This seems to be the first intuitive reading. The second interpretation allows the possibility that Ṣadr was attempting here to develop a new model from scratch.

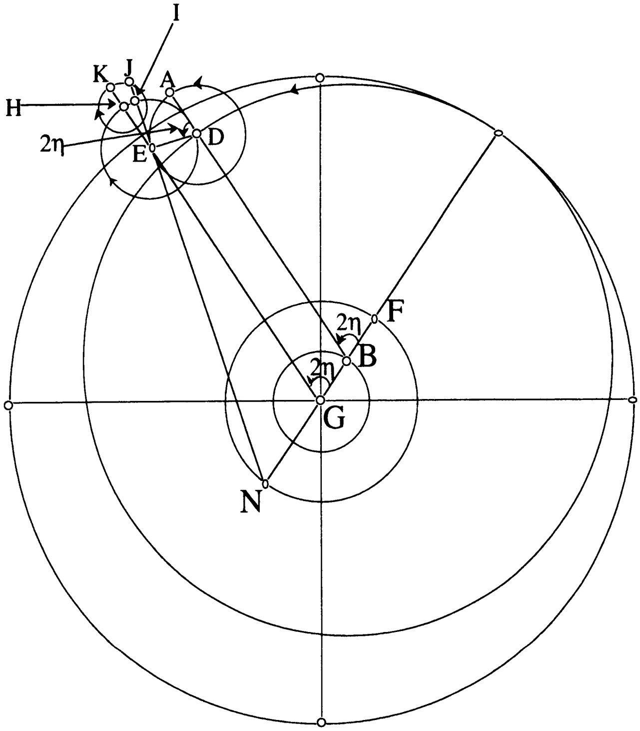


FIGURE 34

Figure 34 is the model proposed by Ṣadr assuming the first interpretation of the text. Point B is the center of the eccentric, whereas point F is the center of this circle in the Ptolemaic model. The first and second epicycles produce exactly the same effects that Shīrāzī's model produces, namely solve the problem of non-uniform motion by bisecting the Ptolemaic eccentricity at point B, and then by adding a compensating epicycle with center E to bring the motion of point E very close to the corresponding center in the Ptolemaic model, and thus allow point E to rotate uniformly around the center of the world G, while the position of the epicyclic center is maintained at a negligible distance from the center predicted in the Ptolemaic model. This model does indeed satisfy the Ptolemaic requirement, because it retains the crank mechanism, which allows the actual epicycle of the moon to recede to a distance of 60 parts from the center of the world at apogee, and to be brought nearer to the center of the world at perigee by $2s = 20;38$ parts, in the same units that make the radius of the inclined sphere 60 parts.

Now, if Ṣadr intended to solve the problem of the prosneusis point by adding another small epicyclet of radius 0;52 parts to the epicycle in the model of Shīrāzī, while retaining the rest of the latter's model, then the resulting configuration would be as follows:

Point *H* in figure 34 is the apparent epicyclic apogee, whereas point *I* is the mean one. If we assume a circle with center *H*, such that line *GEH* intersects it at point *K*, and line *NI* at *J*, then the rotation of point *K* along this circle to point *J* displaces the line from which the mean anomalistic motion is measured from position *GEH* to position *NEI*, and therefore produces the effect of the prosneusis point in the Ptolemaic model.

What remains to be done is to decide on the size and speed of this third circle. The dimension that Ṣadr gives is a radius equal to 10;19 parts, if the radius of the epicycle were equal to 60 parts. But since this last radius is not equal to 60 parts but 5;15 parts, the actual radius of the third epicycle will be about 52 minutes of the same units that make the radius of the inclined orb equal to 60 units. Moreover, this small epicycle rotates in a clockwise direction, at the same speed as the eccentric.

Figure 35 is an enlarged sketch of the three epicycles of the model of Ṣadr. The first uniform rotation of the first epicycle around its center *D* carries the epicyclic apogee to point *E*. Angle *ADE* will thus be equal to twice the mean elongation. The second uniform rotation of the second epicycle around its center carries the apparent epicyclic apogee from point *H* to point *H'*. Angle *HEH'* is the anomalistic motion. Finally, the third small epicycle carries point *K'* to point *J'*, and angle *K'H'J'* equals twice the first equation. The compounded motion of the second and third epicycles are then equivalent to the motion in anomaly plus the first equation resulting from the prosneusis point.

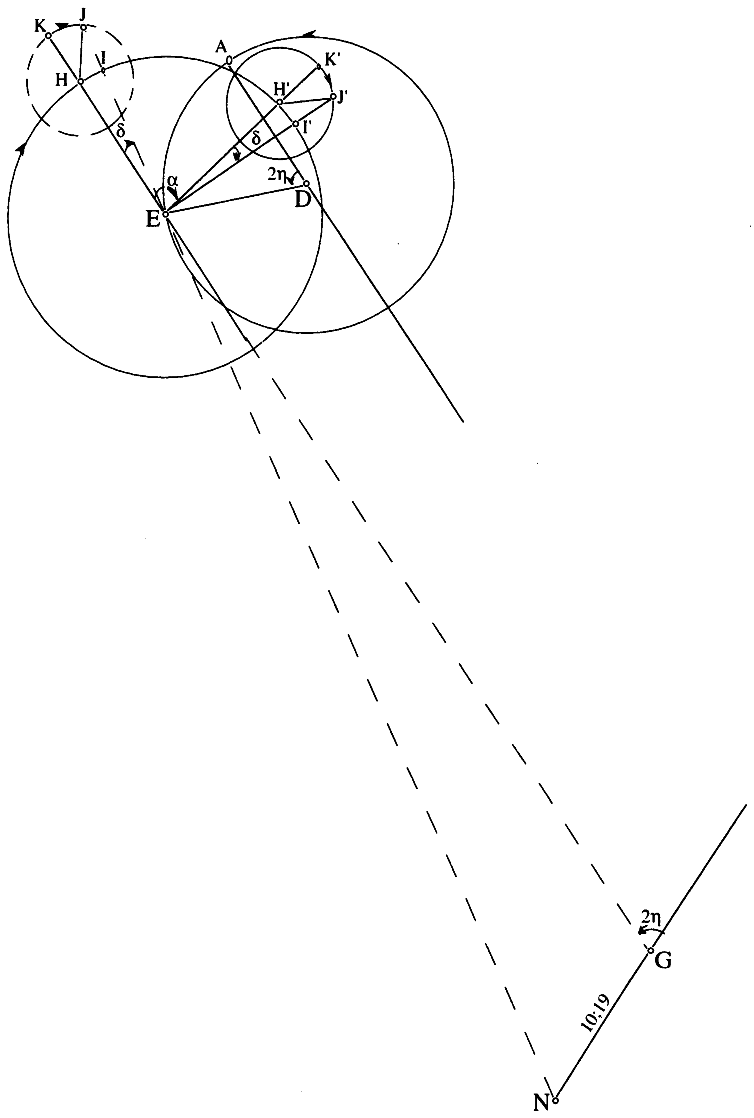


FIGURE 35

Ṣadr's choice of parameters for the third epicycle can now be understood: triangles *HEJ* and *GEN* in figure 35 are similar, and therefore the ratio of *HJ* to *EH* is equal to the ratio of *GN* to *EG*. Now if we assume the length of *EG* to be 60 parts, and given that *EH* equals 5;15 parts, and *GN* equals 10;19 parts, then *HJ* is 54 minutes (compared to the 52' figure given

by Ṣadr.) Moreover, angle *HEJ* = angle *H'E'J'* = the first equation, and the maximum value of this angle is obtained when angle *ENG* = angle *EJH* = 90°. In this last case if we assume the radius of the new eccentric is equal to the Ptolemaic radius, that is, *BD* = 60 - 10;19 = 49;41 parts (figure 34), then the maximum value of the first equation obtained by calculation is 12;34°, compared to a maximum value of 13;9° in the Ptolemaic model, and to a value of 12;51° obtained through Ṣadr's computations using that same model (see paragraph [12] above).

It is also clear from figure 35 that the value of the equation is added to the anomaly in the upper part of the third epicycle, and is subtracted in its lower part.

The model thus produced would solve the problems of the Ptolemaic model, while remaining close to its predicted configuration as far as the angular displacements are concerned. Assuming this interpretation of Ṣadr's text, however, will produce a model that suffers from one major drawback: one can easily show, in figure 34, that at perigee the visible epicyclic radius has to be equal to that of Ptolemy's epicycle minus the radius of the small epicyclet with radius *H*. Similarly, the same Ptolemaic epicyclic radius has to be increased at apogee by the same amount. This means that when the moon is at the apex of the small epicycle, that is, at the apogee, then the apparent radius of the epicycle looks bigger than it actually is, while at perigee it looks smaller. This is a clear divergence from the Ptolemaic model, and Ṣadr does not account for the variation in the size of the actual epicycle, nor does he explain the resulting contradiction with the observations. Moreover, according to this interpretation, the variation in the lunar distances from the center of the world at apogee and perigee would be even larger than the already problematic variation in Ptolemy's model.

The alternative interpretation is to assume that Ṣadr is not modifying Shīrāzī's model, as one would have assumed at first glance, and suppose instead that he is thinking of a new model, where the only feature is the addition of this new small epicyclet to the lunar epicycle, as in figure 35.a. This in fact is the line of thought followed by Ṣadr's contemporary Ibn al-Shāṭir, and later on by Copernicus (On the work of Ibn al-Shāṭir see Abbud; on Copernicus see Swerdlow-Neugebauer, pp. 196-197).

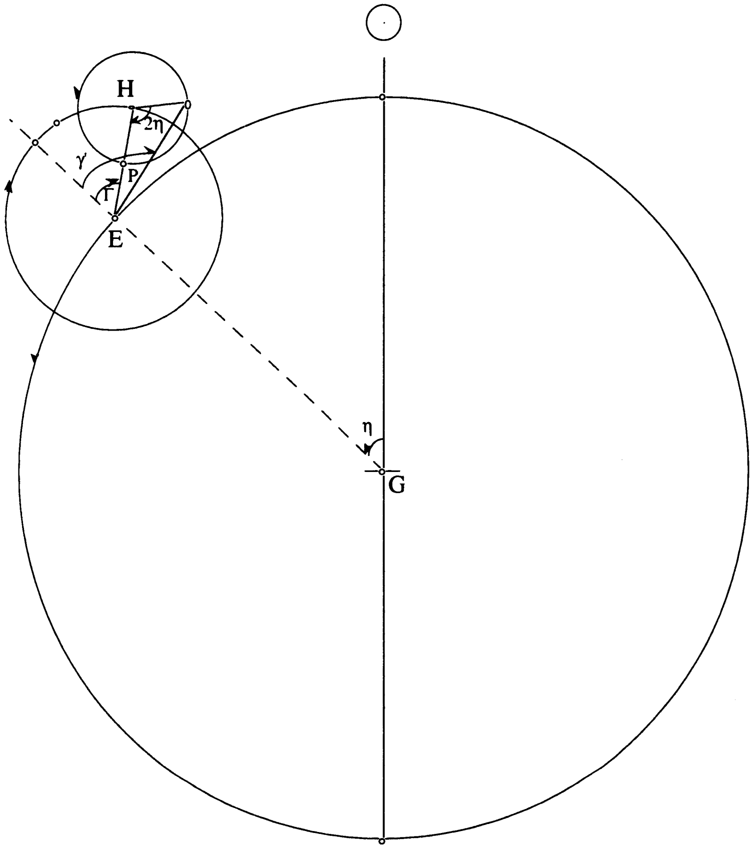


FIGURE 35.a

The difficulties with this interpretation, however, are obvious: (1) Ṣadr is not explicit on the number of spheres he wished to have in his new model, and whether he would retain both the inclined sphere and the eccentric sphere. For this model to work, we have to assume that, like Ibn al-Shāṭir, Ṣadr would dispense with both spheres and replace them with a concentric sphere whose radius is 60 parts. (2) Also, for this model to work, one has to understand Ṣadr's use of the term apex (*dhurwa*) of the small epicyclet in a counter-intuitive sense, for he must surely intend to use that epicyclet in order to increase the size of the actual epicycle at perigee and decrease it at apogee. For that to take place, and for the small epicyclet to move at its apex in the same direction as the actual epicycle, as Ṣadr says, then the apex of the small epicyclet must be taken to be in the lower half of the epicyclet, which is not the usual interpretation of the epicyclic apex.

As for the relative dimensions of this new model, they are not clear either. The radius of the small epicyclet is given as being equal to the radius of the moon, whose value is not given, plus the maximum first equation, which is given as 10;19. This last value is quite different from the Ptolemaic 13;9 reported in the *Almagest* (V, 8) as the maximum value of the first equation. Similarly, the radius of the small epicyclet, given as 0;52 in units that make the radius of the inclined sphere 60, is too small to affect the required change in the size of the epicycle at quadrature, if the radius of that epicycle is taken as 5;15 in the same units. If that were true, then the radius of the epicycle would become 5;15 + 0;52 = 6;7 which subtends an angle of 5;51° at the center of the world which is far less than the required 7;40°. Moreover, if the solution of the prosneusis problem is intended with the small epicyclet, as was the case with Ibn al-Shāṭir and Copernicus, then a small radius of 0;52 would subtend with the radius 5;15 of the epicycle an angle of 9;30,6° only, which is far less than the required 13,9° recorded in the Ptolemaic tables.

At this point it is not clear how Ṣadr expected his new model to work in harmony with the Ptolemaic observations, nor is it clear whether he was considering a larger epicycle than the Ptolemaic one. Whatever is the case, it is still interesting to note that this Central Asian astronomer was already experimenting independently with new ideas to apply to the lunar model along lines that were followed much more successfully by Ibn al-Shāṭir and Copernicus, namely by adding a small epicyclet to the lunar epicycle. It is rather unfortunate that we do not have a clearer idea of the other parts of this model.

[32] The final variation that is mentioned in this chapter results from the fact that while the above models assume that the moon is in the plane of the inclined orb, it is actually measured on the parecliptic. Thus, a further adjustment is needed to locate the position of the moon on this last orb. Ṣadr notes, however, that this adjustment is negligible and need not be considered (For the corresponding sections see *Tadhkira*, p. 159, and *Tuḥfa*, f. 89v-90r. This same problem is raised by Ibn al-Shāṭir in his *al-Zīj al-Jadīd*; in this *zīj* the above variation, for which a table is computed, is called *naql al-qamar*).

CHAPTER 6

[1] The title of this chapter resembles that of the corresponding chapter in the *Tuḥfa*, which also restricts its contents to the longitudinal motions of the three superior planets, namely Saturn, Jupiter, and Mars. The corresponding chapter in the *Tadhkira* is also concerned with the longitudinal motions of the planets, but this concern is not mentioned in the title. Moreover, Ṭūsī includes the inferior planet Venus with the above superior planets, since their models are similar, whereas the other inferior planet, namely Mercury, is treated in a separate chapter, on account of the complexity of its model (for the corresponding chapters see *Tuḥfa*, f. 103v-114v, and *Tadhkira*, pp. 179-87).

The models in all the above works are not presented separately; rather, one geometric model is given for all, whereas Ptolemy introduces a separate, though similar, model for each planet (see *Almagest*, Books IX-XI).

[2]-[3] A superior planet, according to Ṣadr, is observed to rise before the sun (morning star); later, the sun rises, and it gradually approaches the planet, up to the point where they come into conjunction with each other; during conjunction the planet is invisible. The planet then becomes visible again, indicating that the sun is at a reasonable distance from it, and it remains visible for some time after the sun sets. The above, therefore, indicates that the sun moves faster than the planet. Figure 36 is a schematic representation of the relative motions of the sun, earth, and a superior planet. Let point E be the center of the earth, point S the center of the sun, and point P that of the planet. Since we are considering the superior planets, then the distance between the sun and the earth is smaller than the distance between the earth and the planet, and EP is greater than ES. Now in the parallelogram $ESPC$, $ES = CP$, and $EC = SP$. Thus the motion of the planet P around the earth E can be broken into two components EC and CP, which are equal respectively to the motion of the planet around the sun and the motion of the sun around the earth.

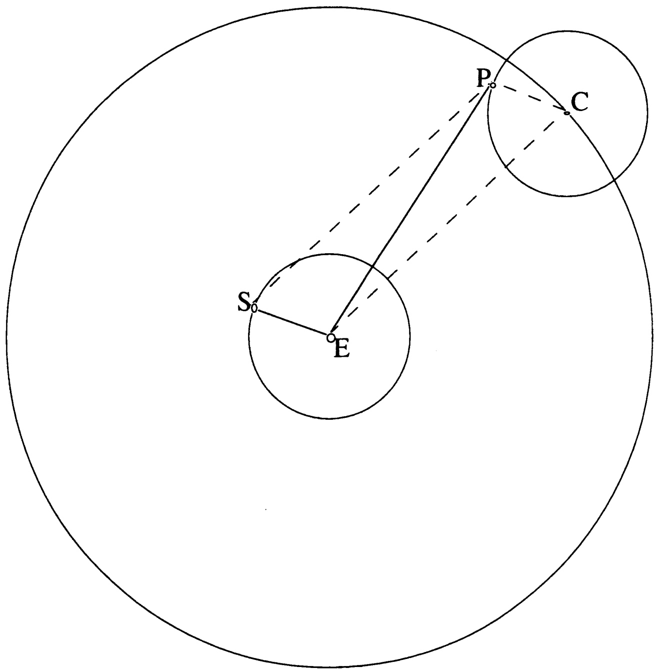


FIGURE 36

Having observed that the sun is faster than the superior planets, one sees that in figure 36, the motion of S around E is faster than the motion of P around E. Therefore, the motion of P around C is faster than C around E. Thus, when P is on the upper part of the circle with center C, the motion is said to be direct, i.e. the motions of P and C are additive, since both are in the same direction. On the other hand, when P is on the lower part of this circle, then the motion is subtractive; and since P is faster than C, then P appears to move backward with respect to E, i.e., it retrogrades.

During direct motion P is in the upper part of the circle with center C, and hence S is between E and P. This means that during direct motion the sun and the planet fall on the same side with respect to the earth, meaning that conjunction between the sun and the planet occurs during this motion, and that the planet becomes invisible around such a conjunction. During retrogradation, however, P falls between C and E, and thus E falls between S and P. Therefore, during retrograde motion, the sun and the planet are on opposite sides with respect to the earth, and no conjunction can occur between them, meaning that the planet is always visible during this motion.

Another observation noted by Ṣadr is that the apparent size of the planet around the middle of the direct motion section is smaller than the apparent

size at the middle of the section where the retrograde motion takes place. Due to its conjunction with the sun, the planet is not visible at the middle of the direct-motion section; hence Ṣadr's use of the term "around" rather than "at". Now, this observation indicates that the planet is farther away from the earth during direct motion.

Furthermore, the days during which the planet has a direct motion are found to be more numerous than the days during which it has a retrograde motion. Ṣadr, like his predecessors, thus posits an epicycle which produces the above mentioned effects.

(For the corresponding sections see *Tadhkira*, pp. 179-83, and *Tuḥfa*, f. 103v-106r.)

[4] This section refers to a comment Shīrāzī makes in his *Tuḥfa* (see *Tuḥfa*, f. 104v). Simply put, he maintains that an eccentric orb can produce retrograde motion, thus it is not enough to infer an epicycle from observing such retrogradation. This epicycle, however, can be inferred from the further observation that the maximum value of the equation is variable, since in this case the radius of the epicycle is seen through different angles, depending on the distance of the center of the epicycle from the center of the universe.

[5] The time between the recurrence of two similar phenomena--such as the recurrence of the same speed, the same slowness, or the invisibility of the planet--is found to vary, such that these occurrences could occur at any part of the ecliptic orb. Therefore, the deferent has to be an orb which encompasses the earth, so that the above occurrences could slide along all parts of the ecliptic orb; moreover, this deferent has to be eccentric, so that these occurrences do not recur at precisely the exact same locations, or after the same periods of time.

(For the corresponding sections see *Tadhkira*, p. 179-81, and *Tuḥfa*, f. 104v-105r.)

[6] The same parameters given by Ṭūsī and Shīrāzī for the motion of the eccentric are quoted by Ṣadr in this section (see *Tadhkira*, p. 181, and *Tuḥfa*, f. 105r.) The parameters given by Ptolemy for the above daily motion are 0;2,0,33,31,28,51 degrees for Saturn, 0;4,59,14,26,46,31 degrees for Jupiter, and 0;31,26,36,53,51,33 degrees for Mars (see *Almagest*, IX, p. 426.)

[7] The sun thus moves faster than the centers of the epicycles. Oppositions and conjunctions, however, still occur at the epicyclic apogee and perigee respectively. Therefore, the effect of the epicyclic motion is to bring back the planet from alignment with the sun at conjunction, to yet another alignment at opposition. This means that the motion of the epicycle is equal to the difference between the mean motion of the sun and the mean motion of the deferent (for the corresponding sections see *Tadhkira*, p. 183).

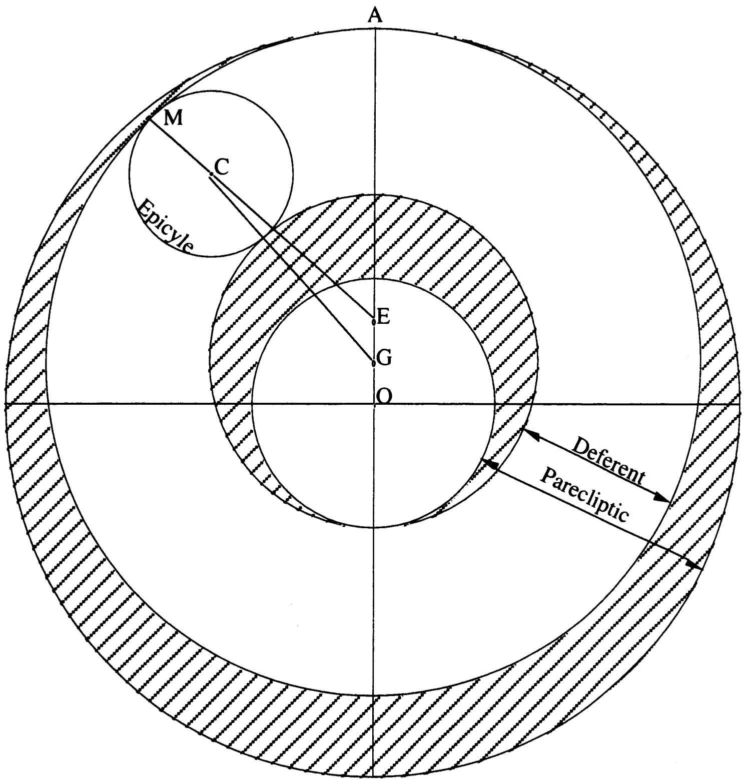


FIGURE 37

Figures 37 and 38 are respectively a solid body and a circle representation of the orbs of the superior planets. The outermost solid in figure 37 is the parecliptic orb (solid 1). Solid 2 is embedded in the parecliptic and is the eccentric deferent which carries the center of the epicycle. The last solid is the epicycle (solid 3) on which the planet is carried. The center of solid 1 is point O, which is the center of the universe, and the motion of this solid is similar to the motion of the fixed stars (i.e., the same as precession). The center of the eccentric deferent which moves, in a counter-clockwise direction is point G. The uniform motion of this deferent, however, is around point E rather than point G, G being halfway between points O and E. Finally, the epicycle also moves in a counter-clockwise direction around point C, such that the uniform motion of this epicycle is measured from the mean epicyclic apogee M, which is the intersection of line EC with the epicycle, rather than on the true epicyclic apogee T, which is the intersection of line OC with this epicycle (see figure 38).

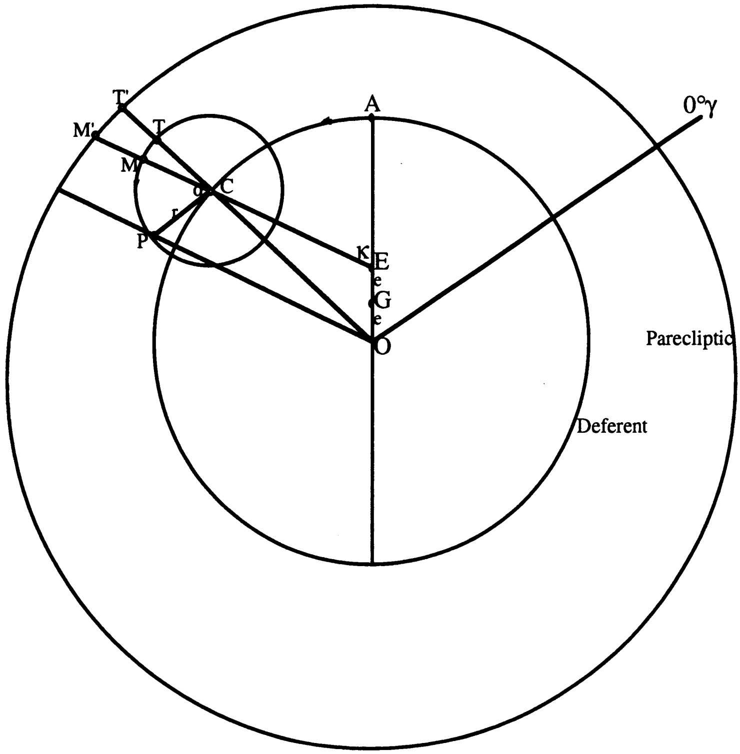


FIGURE 38

The parameters given by Ṣadr for the orbs of each of the three superior planets are similar to those given by both Ṭūsī and Shīrāzī. In other words, it is once more clear that no attempt is made by Ṣadr either to verify or modify the observational data, which he, like his two predecessors, takes for granted. Given that $EG = OG = e$, the radius of the epicycle is r, κ is the motion of the eccentric around point E, and the radius of the deferent is equal to 60;0 parts, then the above parameters are as follows:

Saturn: e = 3;25 parts, r = 6;30 parts, and κ = 0;2°/day

Jupiter: e = 2;45 parts, r = 11;30 parts, and κ = 0;5°/day

Mars: e = 6;0 parts, r = 39;30 parts, and κ = 0;31°/day

[8] The variation referred to in this section is angle COP in figure 38, and is the angle subtended by diameter CP at the center O of the universe. The maximum value of this variation, which is called the second equation, is when lines CP and OP are perpendicular. In this case the sine of angle COP is equal to the radius of the epicycle, but only if this measurement is taken when the center of the epicycle is at the mean distance from the center

of the universe, i.e., when OC = 60;0 parts. This takes place when triangle OCG is isosceles. The reason why this measurement is taken at mean distance rather than at the apogee, as is the case with the moon, is that the superior planets are not visible at the apogee, since they are be in conjunction with the sun, whereas the moon is clearly visible at its epicyclic apogee.

Now, since both the deferent and the epicycle have counter-clockwise rotations, their motions are additive as long as the planet is in the upper part of the epicycle, and they are subtractive when the moon is in the lower part.

(For the corresponding sections see *Tadhkira*, p. 171-3, and *Tuḥfa*, f. 111r.)

[9] The second variation accounts for the fact that the second equation mentioned above is measured at the mean distance of the center of the epicycle from the center of the earth; thus this second equation has to be reduced when the distance is greater, and increased when it is smaller. The mean angle which the epicycle radius subtends at mean distance is tabulated, and next to it are the tables listing the amount to be added or subtracted in order to get the above angle at positions other than the mean. Such tables are standard in Islamic *zījs*, following the tradition of the Handy Tables (see Kennedy, 1983, pp. 636-651).

(For the corresponding sections see *Tadhkira*, p. 173, and *Tuḥfa*, f. 111r.)

[10] The third and final variation refers to the fact that the anomalistic motion is not measured from the true apogee (point T in figure 38) but from the mean epicyclic apogee M. The angle which Ṣadr is referring to here is angle OCE, which is equal to angle TCM, and which is the angle through which the true apogee is displaced on the circumference of the epicycle (for corresponding sections see *Tadhkira*, p. 173, and *Tuḥfa*, f. 112r).

[11]-[12] Without elaborating on the configuration which he discusses in the above sections, Ṣadr proceeds in this section to present an alternative model for the motion of the superior planets. Although Ṣadr does not say exactly what he objects to in the Ptolemaic model thus presented, it is nonetheless clear that the two problems that his model proposes to solve are the problem of having the uniform motion of the center of the epicycle measured around a point which is not its center, namely the equant E, and the problem of measuring the epicyclic motion from the mean apogee rather than from the true one.

The method used by Ṣadr is not new; it is the same method which was developed by 'Urḍī, and which was later used by Shīrāzī to solve the problem of the equant (for a discussion of 'Urḍī's method see Saliba, 1981; for the use of this method by Shīrāzī see Saliba, "Original Source," 1979). It should be noted, however, that Ṣadr does not acknowledge either of the above sources.

The method used employs an additional epicycle which carries the center of the planet-carrying epicycle, such that its center rotates on an eccentric whose center is halfway between the Ptolemaic center and the equant. Thus in figure 39 the center of the new eccentric is point G', such that $G'E = G'G$. The new epicycle is the small circle of center C', and it carries the center of the planet carrying epicycle, namely point C. The small epicycle and the eccentric both rotate at the same speed in a counter-clockwise direction.

Initially, the center of the small epicycle is point A', and the center of the planet-carrying epicycle is point A at the perigee of the first one. Point A clearly coincides with the initial position of the planet carrying epicycle in the Ptolemaic model. As the eccentric moves point A' through an angle κ to point C', point A moves through a similar angle on the epicycle to reach position C. The motion of the eccentric is measured around point G', so angle $A'G'C' = \kappa$. On the other hand, the motion of the small epicycle is measured around point C', so angle $G'C'C = \kappa$. Now $C'C = G'E = e/2$, where e is the eccentricity of the Ptolemaic model; therefore, 'Urḍī's lemma applies to $CC'G'E$, since two sides and two interior angles are equal (see above), and therefore EC is parallel to $G'C'$.

It is clear from figure 39 that the center of the planet-carrying epicycle in this new model coincides with the center of the epicycle in the Ptolemaic model at the two boundary conditions, i.e. at the eccentric apogee and perigee. At all other positions the two centers are very close, and the new center is a fairly accurate approximation to the Ptolemaic one. On the other hand, angles $A'EC$ and $A'G'C'$ are equal, thus the rotation of the new center appears to be uniform around the equant of the Ptolemaic model, while it is at the same time produced by the uniform rotation of the new eccentric and the new epicycle around their respective centers.

(For the corresponding sections see *Tuḥfa*, f. 108r-108v.)

[13] The surrounding epicycle moves all points on the planet-carrying epicycle and not only its center. A retaining orb serves to realign the planet-carrying epicycle such that its apsidal line passes through the equant. Alternatively, the epicycle can be made to rotate through the sum of the motion of the surrounding epicycle and the motion in anomaly, in which case no retaining circle is needed (for a more detailed discussion of this point see *Tuḥfa*, f. 105r-105v).

14] Ṣadr rightly notes in this paragraph that the problem of the prosneusis point does not apply in the case of the superior planets, since the apsidal line of the epicycle passes through a fixed point, rather than a moving point as in the case of the moon, and since the motion of the center of the epicycle is uniform around this fixed point.

In figure 38, the second equation is the angle subtended by the radius of the epicycle at the center of the earth; this is angle POC, and it is the same as angle POT. Now, the mean anomaly is measured from the mean

epicyclic apogee, i.e., from point *M*; therefore, for the configuration in figure 38, the second equation is determined by arc *PT* on the epicycle, which is the sum of the mean anomaly and the variation between the mean and the true epicyclic apogees. Thus, as long as the epicycle is descending from the eccentric apogee, as is the case in figure 38, the above variation is additive to the anomaly, but subtractive when the epicycle is ascending.

The mean longitude, on the other hand, is measured from the beginning of Aries to the intersection of line *ECM* with the parecliptic. It is clear, therefore, that the true longitude of the epicyclic center is obtained by subtracting the variation between the true and mean epicyclic apogees from the mean longitude, when the epicycle is descending, and conversely when it is ascending.

[15]-[16] This paragraph addresses a problem similar to the problem raised in the chapter on the orbs of the sun (see above): how is it possible to add arcs when they belong to different circles, namely the epicycle and the parecliptic? The answer is that the angle which is added to the anomaly, or subtracted from it, is measured around the center of the epicycle. Once that is done, we find the angle around the center of the universe which corresponds to the above measured angle, and this we add to or subtract from the mean longitude, which is measured around the center of the earth.

The discussion here is similar to the discussion in relation to the sun (see chapter 4 above).

[17] This section is similar to the corresponding section in the *Tadhkira* (see *Tadhkira*, p. 185), and it explains a feature which is specific to Mars; provided the spheres are nested close to each other, at mean conjunction the sun will be at epicyclic apogee (see above). Thus, the smallest distance between the sun and Mars in this case is when the sun is at eccentric apogee and the epicycle of Mars at eccentric perigee, in which case the distance between Mars and the sun is the distance between the epicyclic apogee and perigee, i.e. twice the radius of the epicycle; the minimum distance in this case is, therefore, 79;0 parts.

At opposition, Mars is at the epicyclic perigee, and the greatest distance between Mars and the sun is when both the sun and the epicycle of Mars are at their respective eccentric apogees. The distance between Mars and the sun is thus equal to the diameter of the parecliptic of the sun, plus the thickness of the complementary solid of the sun, plus the thickness of the complementary solid of Mars. The thickness of a complementary solid is equal to twice the eccentricity, hence the values 12 and 4 parts for those of Mars and the sun. The diameter of the parecliptic of the sun is twice the distance from the center of the earth to the eccentric perigee, which is equal to 60 - 39;30 + 6 = 26;30 parts. The maximum distance between Mars and the sun during opposition is thus (26;30 x 2 + 12 + 4) parts, adding up to a sum of 69 parts.

The above illustrates that the sun and Mars are closer at opposition than at conjunction, the maximum distance between them in the first case being 69 parts, while the minimum in the second case is 79 parts.

CHAPTER 7

[1] This chapter too has a title similar to the corresponding chapter in the *Tuḥfa*, whereas the chapter in the *Tadhkira* is concerned only with the orbs of Mercury (see *Tadhkira*, pp. 165-77, and *Tuḥfa*, f. 114v-173v).

[2]-[4] The two inferior planets, namely Venus and Mercury, are closer to the sun than the earth. If in figure 40, point E is the center of the universe, and point S is the mean sun, then the planet rotates on the smaller circle with center S in the direction marked on the figure, such that the planet and the sun are always on the same side from the earth. This means that on both sides of the circle with center S the sun and the planet come into conjunction with each other. Now the planet is not visible at and around conjunction with the sun; therefore, during every rotation around the sun, the planet is invisible twice, and conversely is visible twice.

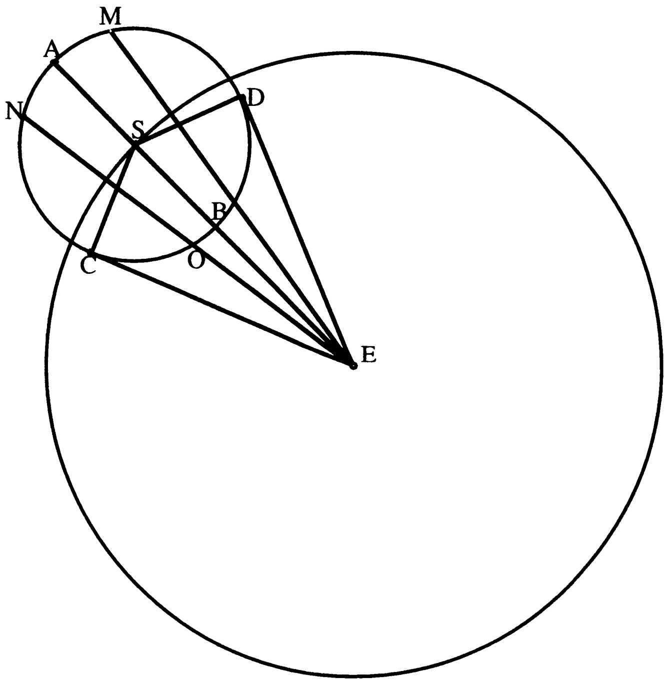


FIGURE 40

Let the points O, L, M, and N mark the points at which the planet crosses from the visible to the invisible phase: the planet is invisible while it is on

arcs *OL* and *MN*, while it is visible on the two remaining arcs. Moreover, in its daily rotation, arc *LDM* rises before the sun; hence the planet is a morning star while it travels on this arc, whereas it is an evening star while it is on arc *NCO*.

Therefore, if we trace the motion of the planet on the circle *S*, we get the following: at point *A*, the planet rotates in the same direction as that of the sun; thus it will be at its maximum speed; at this point, however, the sun and the planet are in conjunction, and the planet is invisible. The planet travels faster than the sun, thus going ahead of it and becoming visible at point *N*. Between points *N* and *C*, the planet slows down, until it appears to stop at point *C*, at which point it appears to move in a reverse direction until it reaches point *O*, where again it becomes invisible. Next, the planet reaches its maximum retrograde speed at point *B*, and then it starts to slow down until it reaches point *L*, where it becomes visible again. It then continues to slow down until it reaches point *D*, where it appears to stop, and then it starts to move in a forward direction, and picks up speed to reach its maximum visible speed at point *M*, and its maximum direct speed at point *A*.

(For the corresponding sections see *Tadhkira*, p. 165, and *Tuḥfa*, f. 114v.)

Ṣadr entirely omits all the above description, and mentions instead that the maximum speeds occur at the mid-points of the forward and retrograde motions. He then specifies the maximum angular distances between the sun and Venus, and the sun and Mercury (for the corresponding sections see *Tadhkira*, pp. 165, 179, and *Tuḥfa*, f. 114v), and moves on to note that the period of direct motion is longer than the period of retrograde motion, and that the apparent size of the planet is smaller during direct motion. Therefore, Ṣadr concludes that each of the two planets must be carried on an epicycle, such that the upper part of this epicycle moves counter-clockwise, and its radius is the one to which the maximum angular distance of each planet corresponds (for the corresponding sections see *Tadhkira*, pp. 167, 169-71, and *Tuḥfa*, f. 115r, 118v).

[5] Now, if one observes the conditions at a certain location during one rotation, for example the condition when the planet is at maximum speed, and then measures the location at which the same conditions recur during the following rotation, one finds that the two locations do not coincide. Therefore, Ṣadr deduced, as did his predecessors, that the epicycle must be carried on an eccentric whose speed is equal to the mean motion of the sun, such that the center of the epicycle and the center of the sun coincide (for the corresponding sections see *Tadhkira*, pp. 167-9, and *Tuḥfa*, f. 115v).

[6] In this section a parecliptic which moves at the same speed as the fixed stars is posited. This parecliptic will cause such points as the eccentric apogee--where the center of the epicycle is at its slowest speed, and where

the duration of this slow speed is short--to move with the fixed stars (for the corresponding sections see *Tadhkira*, p. 165, and *Tuḥfa*, f. 115r).

[7] If in the case of Venus a situation is obtained at a certain point, such as the position where the speed of the center of the epicycle is maximum, then the opposite situation, such as the minimum speed of the center of the epicycle, is obtained at the point which is diametrically opposite to the first one. The model of Venus is, therefore, similar to the models of the superior planets (for the corresponding section see *Tuḥfa*, f. 116r).

The case of Mercury, however, is different, since the Ptolemaic observation entails that the position of its closest distance from the center of the universe, which is inferred from the greatness of the apparent size of the radius of the epicycle, is not diametrically opposite to the point where it is at its farthest distance. The eccentric perigee is, rather, located at the two trines with respect to the eccentric apogee (for the corresponding section see *Tadhkira*, p. 165-7, and *Tuḥfa*, f. 116r, 121v).

[8] The case of Mercury is also different from that of the moon, for in the latter the eccentric perigee occurs at quadrature rather than trine (for the corresponding sections see *Tuḥfa*, f. 121v).

[9] Had the path of the center of the epicycle been a circle which rotates about its own center, then all points on its circumference would be equidistant from this center. Had this path been an eccentric, then it would have only one perigee. But since Mercury has two perigees, then the path of the epicyclic center is neither a concentric nor an eccentric circle. Rather, this path must be an elliptical or an egg-like shape with two apogees which are diametrically opposite to each other (for the corresponding section see *Tuḥfa*, f. 121v).

[10]-[11] Based on the above, Ṣadr and his predecessors deduced that the orbs of Mercury must include two eccentric orbs. The first of these is the director, and it is embedded in the thickness of the parecliptic, such that its center is 6 parts away from the center of the universe. The director moves around its center, and it moves the second apogee, in a clockwise direction, at the speed of the mean sun. The second eccentric is the deferent, and it is embedded in the thickness of the director, such that their centers are 3 parts apart. The deferent moves in a counter-clockwise direction at twice the speed of the director. Ṣadr, however, does not mention until later that the rotation of the deferent is measured around the equant center, which is halfway between the center of the universe and the center of the director (see paragraph 14 below). Finally, the epicycle is embedded in the thickness of the deferent, and Mercury is on this epicycle (for the corresponding sections see *Tadhkira*, p. 167-9, and *Tuḥfa*, f. 118v-119r).

Figures 41 and 42 are representations of the orbs of Mercury in solid spheres and simple circles. The largest sphere in figure 41 is the parecliptic, and it rotates about center O in a counter-clockwise direction. The middle

sphere is the director, and it rotates about center G in a clockwise direction. Finally, the innermost sphere is the deferent which carries the epicycle, and which rotates at twice the speed of the director in a counter-clockwise direction. The center of this deferent, however, is itself carried by the director, and it thus rotates on the circle with center G and radius GF. Moreover, the uniform motion of the deferent is not measured around its own center, but rather around the equant center E. Now, if the radius of the deferent circle is taken to be 60 parts, then $OE = EG = GF = 3$ parts.

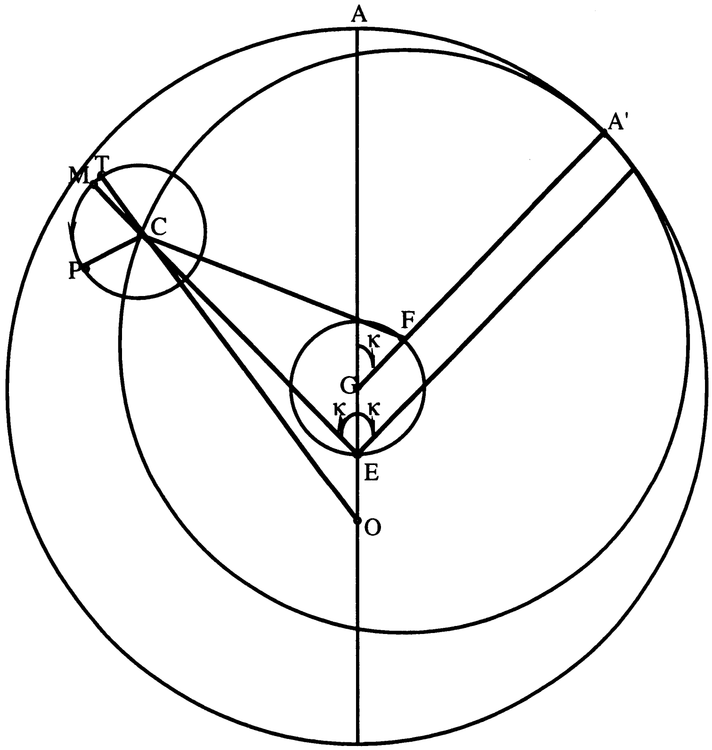


FIGURE 42

Point A in figure 42 is the first apogee, and its motion is similar to that of the fixed stars. Point A' is the deferent's apogee, and it is displaced by the movement of the director through an angle κ. The deferent then rotates through an angle 2κ in a counter-clockwise direction, such that this angle is measured around point E rather than point F. This last movement carries the center of the epicycle through the angle 2κ away from the second apogee. Finally, the anomalistic motion of the planet is measured on the epicycle

away from the mean epicyclic apogee M, rather than from the true apogee T (see paragraph [14] below).

[12]-[13] Ṣadr is interested in finding the actual shape of the trajectory of the center of the epicycle carrying the planet. He does so by comparing this shape with a circle drawn around point G, so that it intersects the said shape at four different points. But the shape suggested is not the correct trajectory that would be obtained if the motion of the center of the epicycle were plotted in the above model. Rather, it is a fair approximation to it.

Ṣadr notes here that the maximum distance of the center of the epicycle from the center of the universe is at the first apogee, and is marked by GA in figure 43. $GA = GO + OF + FA = 6 + 3 + 60 = 69$ parts. Now, when the center of the epicycle moves through 180° along the deferent, it will meet the second apogee at point B. GB is thus equal to $60 - 3 = 57$ parts. Ṣadr then finds that the distance between the center of the director and the center of the epicycle, when it is at either one of the two quadratures, is also 57 parts. Thus we obtain a figure whose span in length is $69 + 57 = 126$ parts, and whose width is $57 + 57 = 114$ parts. Ṣadr immediately proceeds to assume that the path of the center of the epicycle of Mercury is the oval shape of figure 43. A closer examination shows that the center of the epicycle does not trace the elegant path that Ṣadr suggests, rather it traces a pear-like shape which draws the center of the epicycle to a minimum distance from the center of the universe at trines with respect to the apogee A (for a more accurate plot of the trajectory of the center of the epicycle in the model used by Shīrāzī, see Kennedy, 1983, p. 93).

It would still be correct, however, to assume with Ṣadr that the shortest distance between the center of the epicycle and the center of the universe is located between the two points D and T (for the corresponding sections see *Tadhkira*, p. 169, and *Tuḥfa*, f. 146r-147v).

[14] In this section Ṣadr notes that the variations in the model of Venus are similar to those of the superior planets, whereas in the case of Mercury the uniformity of the motion of the deferent is around a point which is halfway between the center of the director and the center of the universe, namely the equant center. Moreover, the epicyclic diameter is also aligned with this point. A separate solution is therefore needed for this case (for the corresponding sections see *Tadhkira*, pp. 171-3, and *Tuḥfa*, f. 128r, 124v).

After noting that Ṭūsī could not solve the problems of the Ptolemaic model for Mercury (see *Tadhkira*, p. 209), and without any mention of the methods developed by Shīrāzī (see *Tuḥfa*, f. 116v-173v), Ṣadr announces that he was able to work out a satisfactory solution for these problems. Again, these problems arise as a result of the following conditions: 1) the motion of the deferent is not uniform around its own center, but around the equant center, 2) the motion of the epicycle in anomaly is measured from the extended line connecting the center of the epicycle with the equant,

rather than from the line which passes through the center of the epicycle and the center of the universe, where the observations were actually recorded.

[15] Ṣadr devises a two-step solution for the above problems. He first makes the motion of the center of the epicycle uniform around the center of the director, while the motion of the deferent on which it travels is also kept uniform about its own center. To do so Ṣadr introduced a deferent (see figure 44) whose center F' is halfway between the center of the Ptolemaic deferent F and the center G of the director. Ṣadr also introduced an additional epicycle which carries the center C' of the planet- carrying epicycle. This additional epicycle has a center J and a radius $JC' = GF' = 1/2\ e$, where e is the eccentricity of the Ptolemaic model, and is equal to 3 parts.

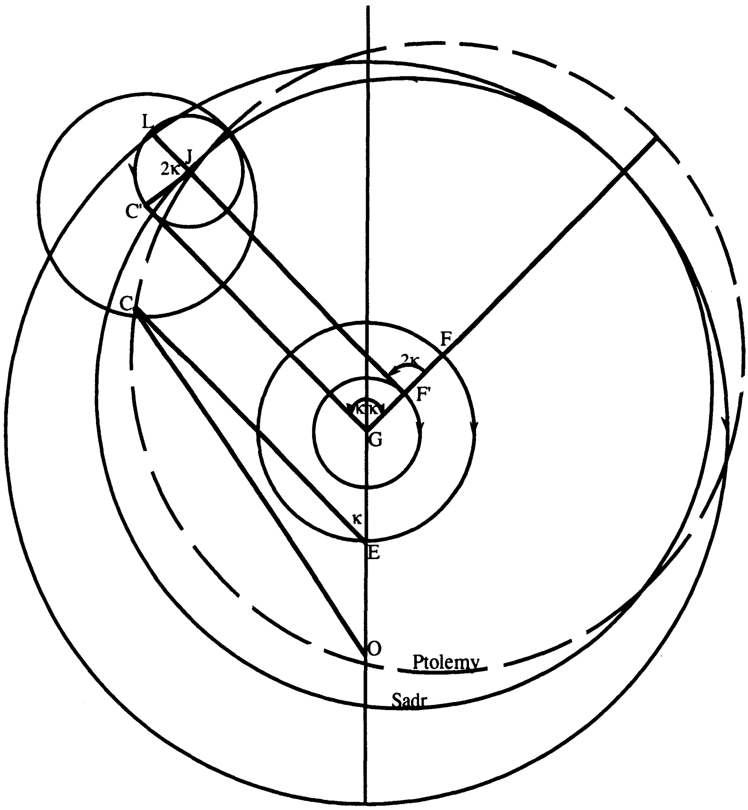


FIGURE 44

Now the director is made to move uniformly about G in a clockwise direction. The deferent is then made to move uniformly around its own center

F' in a counter-clockwise direction at twice the speed of the director. The center of the small epicycle reaches point J. Next, the small epicycle is made to move in a counter-clockwise direction at the same speed as the deferent, thus carrying the center of the planet-carrying epicycle to point C'. As a result of these motions angles $A'F'J$ and LJC' are equal, hence angles $C'JF'$ and $GF'J$ are also equal. Moreover, $JC' = F'G$. Therefore, by using 'Urḍī's lemma which is used in the case of the moon (see above), lines $F'J$ and GC' are parallel, and angles $C'GF'$ and $JF'A'$ are equal. This means that the motion of the center C' of the planet-carrying epicycle is uniform about the center G of the director.

If we move to the second problem, namely that of aligning the diameter of the epicycle from which the anomalistic motion is measured, with the equant, then some transformation must take place so that the present motion, which is uniform around point G according to Ṣadr, is to be perceived as taking place uniformly as well around the Ptolemaic equant E. This means that the variation which was a function of the distance OE in the Ptolemaic model is now a function of the distance OG, which is twice the first distance. Thus, the second problem which Ṣadr attempts solve is reduced to devising a mechanism through which the motion of the center of the epicycle appears to be uniform around the equant, and through which the true epicyclic apogee is displaced to a mean apogee, which is aligned with this equant.

[16]-[23] The second mechanism introduced by Ṣadr is similar to the one which he uses in the model of the moon (see figure 29 above). In figure 45 the three concentric orbs introduced by Ṣadr are drawn. All three orbs are concentric with the director. The rotation of the spheres around their respective axis produces two circles which, according to Ṣadr, form a Ṭūsī couple. Now if the approximation of a spherical couple to a plane one is accepted, then, as in the case of the moon (see chapter 5 above), the set of three spheres will transfer the motion such that it appears to be uniform around a point which corresponds to the Ptolemaic equant center.

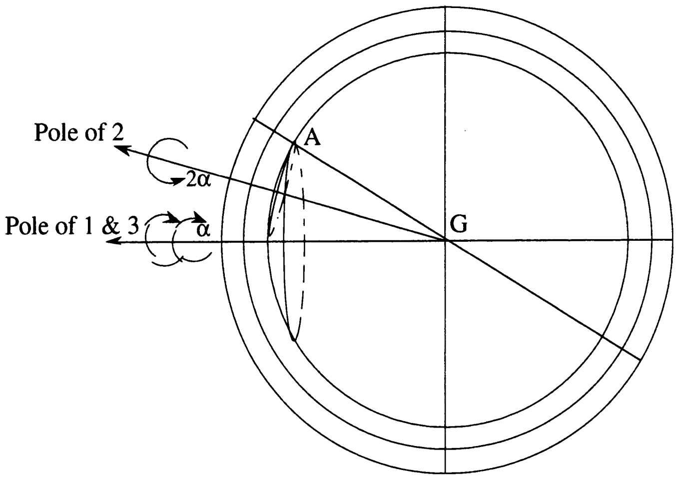


FIGURE 45

To illustrate this, consider figure 45.a: let point G be the center of the director, and point C' the center of the epicycle, which was displaced earlier in the first part of Ṣadr's model (figure 44). Point C' rotates uniformly around G. Now at the apogee of the deferent, the poles of the first and third spheres coincide with the center of the epicycle, while the pole B' of the second sphere falls on the line drawn perpendicular to the plane of the epicycle at point C'. $C'B'$ is equal to half the maximum inclination, i.e., it is equal to half the distance between the original equant center in the Ptolemaic model, and the center of uniform motion obtained in Ṣadr's model. This is 1;30 degrees. As the deferent moves through 90°, the pole C' will move to position C'' in the plane of the deferent, such that the distance $C''A''$ equals three degrees. The center of the epicycle moves to C''. Moreover, the rotation of the third sphere (not shown in the figure) restores the relative positions of the three spheres and of the epicycle. If then we draw a line EC'' it will be parallel to GA'', and the center of the epicycle will appear to rotate uniformly around the equant center E. The figure also shows the position of the center of the epicycle C''' at 90° before the apogee of the deferent, where $C'''E$ is also parallel to GA'''.

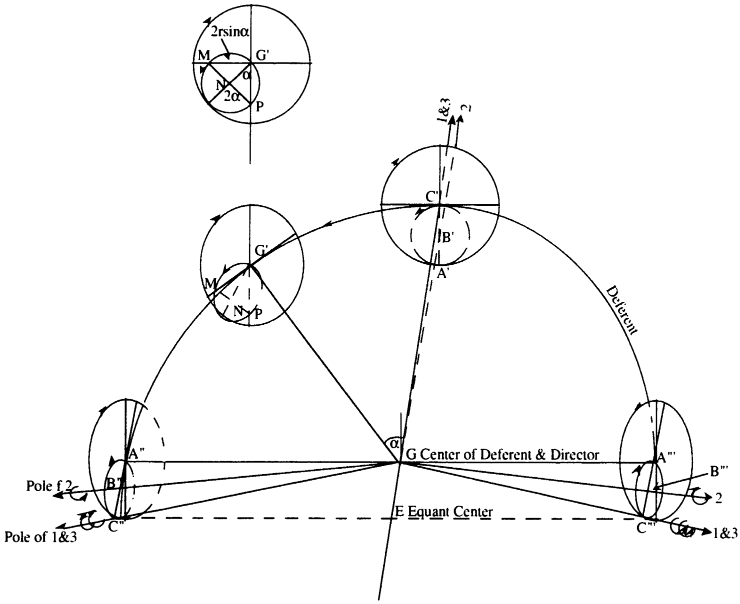


FIGURE 45.a

For the more general case where the center C' moves to M (also in figure 45.a), the displacement of the center of the epicycle from the original position G' at the apogee is MG', and is equal to 2r.sinα, where α is the angle of rotation around the center G of the director, and r is the radius of the small circle of the couple, which is equal to half the distance EG. Therefore, MG' = EG.sinα. Now in figure 45.b, GG' is perpendicular to MG', since the plane of rotation of the poles of the spherical Ṭūsī couple is always perpendicular to the cincture of the epicycle. If next we draw line EL perpendicular to MG', and line GQ perpendicular to EL, then $LG'QG$ is a rectangle, and LG' = QG = EG.sinα. But MG' = EG.sinα, therefore M and L coincide, and ME will be parallel to $G'G$. As a result of the above, the center M of the epicycle always rotates uniformly around the equant center E.

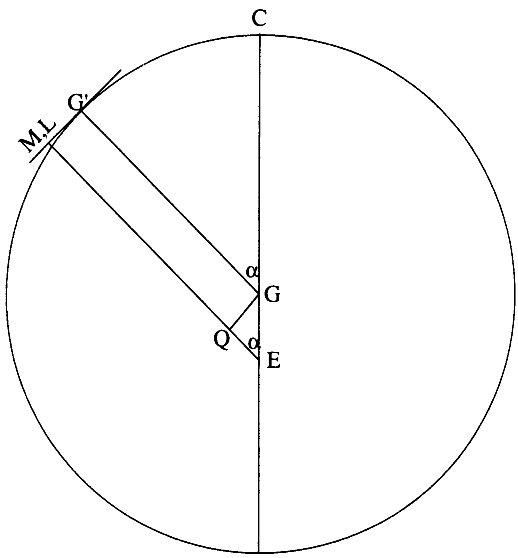


FIGURE 45.b

Now once the above is established, it can easily be proved that the perigee is still be at trine, since this is a function of the uniformity of the motion around the equant, and this uniformity is maintained in Ṣadr's model.

The combined effect of the two steps used by Ṣadr will therefore produce a uniform motion around the center of the director, and an equally uniform motion around the center of the equant. This means that all the circles of this model rotate uniformly around their centers, while the observations underlying Ptolemy's model are also maintained.

CHAPTER 8

This chapter has no title. It deals with the latitude theory of the superior and the inferior planets.

After presenting the models for the motion in latitude, Ṣadr proceeds to present and criticize the models given in the *Tadhkira* and the *Tuḥfa* (for the corresponding sections see *Tadhkira*, pp. 189-95, and *Tuḥfa*, f. 174r-181r.)

In paragraphs one through fifteen Ṣadr describes the Ptolemaic model for the planets' motions in latitude. Figure 46 is a schematic representation of the motion of the superior planets. The path of the epicycle center of each of the superior planets is a circle called the inclined orb, which does not fall in the plane of the parecliptic; rather, these two circles are inclined with respect to each other, and the angle between them has a fixed value i_1. This is called the first inclination.

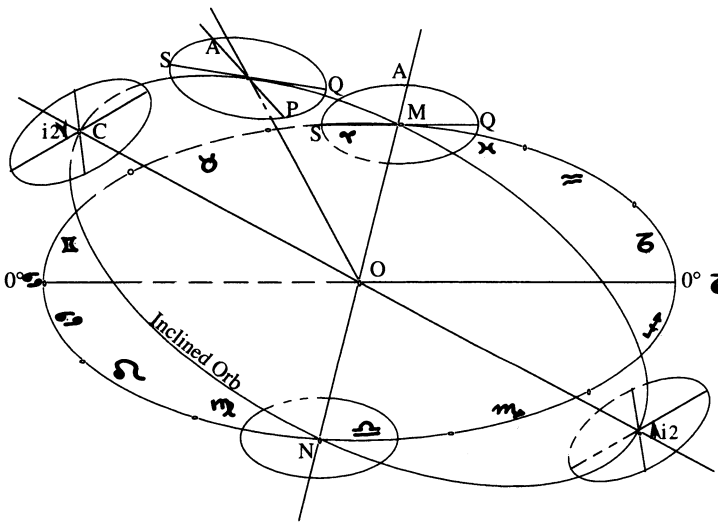


FIGURE 46

The superior planets have a second inclination, which is the inclination of their respective epicycles with respect to their inclined orbs. The second inclination, however, is not fixed, and it oscillates between a maximum northerly inclination, and an equally maximum southerly inclination, passing through a zero inclination, which occurs when the epicycle coincides with the ecliptic at the nodes.

In figure 46, point O is the center of the world, E the center of the deferent, which is in the plane of the inclined orb, and C the center of the epicycle. Points M and N are the two nodes which mark the intersection between the deferent and the parecliptic. When the center of the epicycle is at the ascending node M, the plane of the epicycle coincides with the plane of the ecliptic. In this case, the diameter AP of the epicycle, which joins the apogee and the perigee, falls in the plane of the parecliptic, and thus passes through the center O of the world. As the center C of the epicycle moves away from the node M, the plane of the epicycle starts to rotate around diameter SQ, which is perpendicular to diameter AP. AP thus inclines south of the inclined orb, i.e. toward the parecliptic, and the angle i_2 between the two lines is the second inclination. The plane of the epicycle intersects the plane of the deferent along diameter SQ of the epicycle.

The second inclination reaches its maximum southerly inclination away from the inclined orb when the center C of the epicycle reaches the apogee of the deferent. As C descends from the apogee, the second inclination starts to decrease, and it becomes zero at the second descending node N. The plane of the epicycle then coincides with the plane of the ecliptic. Center C then descends toward the deferent perigee, and the epicycle will have a northerly inclination with respect to the plane of the inclined orb, i.e., it will incline toward the plane of the parecliptic. The northerly inclination reaches its maximum at the deferent perigee, and then it starts to decrease as the center of the epicycle ascends back to the first node.

Figure 47 is a cross-sectional schematic view of figure 46. The maximum values of angles i_2, for each of the three superior planets, as measured at the center C of the epicycle, are clearly different from the values measured from the center O of the world. The epicyclic apogee subtends at O a smaller angle than the epicyclic perigee. Furthermore, the angles at deferent perigee are greater than the ones at the apogee. Thus, for each maximum value of i_2 measured at the center of the epicycle, there are four corresponding values at the center of the world.

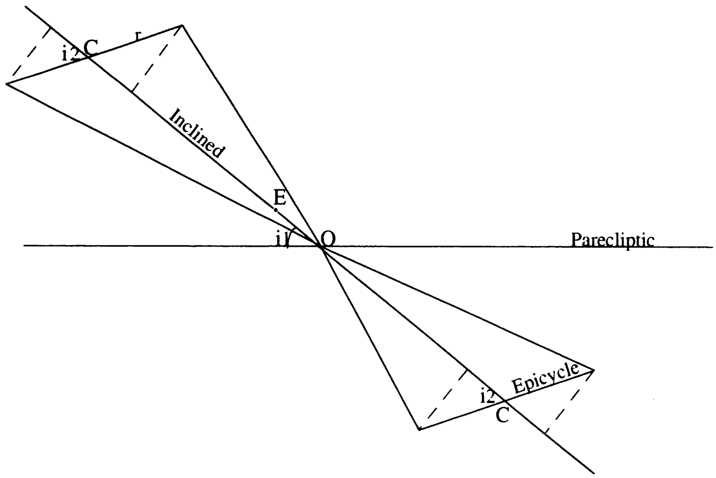


FIGURE 47

Figure 48 shows the different stages of the motion of the inferior planet Venus. The reverse directions are obtained in the case of Mercury. As the figure clearly illustrates, there are three variable inclination angles in this model: the first is the inclination of the inclined orb, in which the deferent plane falls, with respect to the plane of the parecliptic. This is angle i_1, and it varies from zero when the center of the epicycle is at either one of the two nodes, i.e. when the epicycle moves through ninety degrees away from the apsidal line, to a maximum value when the center of the epicycle is at the deferent apogee or perigee.

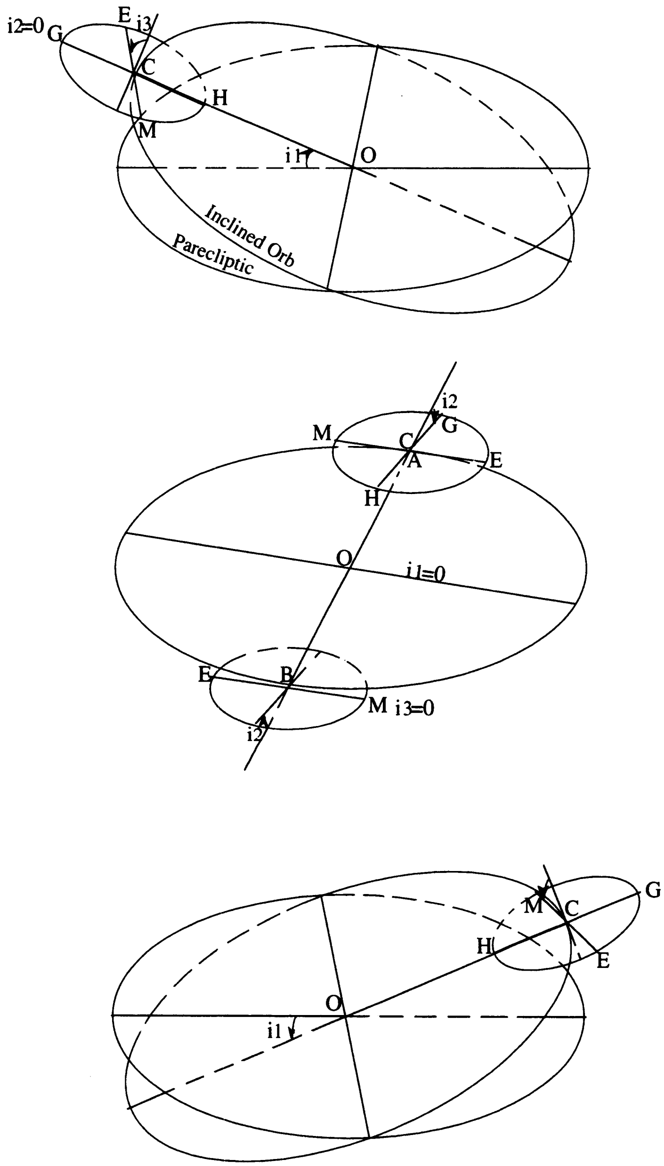

i2=0
G
E
i3
C
H
M
i1
O
Inclined Orb
Parecliptic
i2
G
M
C
A
E
H
O
i1=0
E
B
M
i3=0
i2
M
C
G
H
E
O
i1

FIGURE 48

The second angle is inclination i_2 of the epicyclic diameter *GH* with respect to the line *OC* joining the center of the world to the center of the epicycle. As a result of this inclination, the plane of the epicycle rotates around the diameter *ME* which is perpendicular to the line *OC*. Angle i_2 is zero when the center of the epicycle is at deferent apogee or perigee, and reaches a maximum when this center is ninety degrees away from the apsidal line, i.e. when the first inclination is zero.

Finally, the third inclination is also of the epicyclic plane around an axis which passes through the epicyclic apogee and perigee. This is angle i_3 in figure 48, and it has a maximum value when the center of the epicycle is at the deferent apogee or perigee, while it is zero when the epicycle is ninety degrees away from the apsidal line.

It is clear from the above cursory description why the Ptolemaic model for the motions in latitude should be considered problematic by later astronomers. Indeed, much effort was exerted by Ṭūsī and Shīrāzī to rectify this model, and Ṣadr presents his own model after dwelling at length on their solutions (on the problems of the Ptolemaic latitude theory, and on the solution proposed by Ṭūsī, see Saliba, 1987, pp. 12-19.)

Since neither the solution of the *Tadhkira*, nor that of the *Tuḥfa*, have been studied, and since it is essential to resolve the difficulties of both models before proceeding to study the solutions of Ṣadr, I will therefore refrain from further comment on the present chapter. In the future, I hope to produce a full study of the latitude theories of Ṭūsī, Shīrāzī, and Ṣadr.

CHAPTER 9

[1] This chapter corresponds to Book XII in the *Almagest*, and to chapters II.14 and 16 of the *Tadhkira* and the *Tuḥfa* respectively (see *Almagest*, XII, pp. 555-596, *Tadhkira*, pp. 241-3, and *Tuḥfa*, f. 198r-204r). In the last two works, however, the basic lemmas are presented in earlier chapters, and in both cases the reader is referred to the *Almagest* for a proof of these lemmas (for the lemmas see *Tadhkira*, pp. 137-41, and *Tuḥfa*, f. 56r-59r. Also for a detailed explanation of the these lemmas, and of the general method used by Ptolemy, see Pedersen, pp. 329-354).

[3]-[4] The two cases described in these two paragraphs are illustrated in figures 49 and 50. The first figure shows the line passing through the two mean distances which are determined with respect to distance or linear measure, while the second figure shows those determined with respect to motion. Points M and N in each figure are the mean distance points of the deferent, while points G and H are the mean distance points of the epicycle.

[5]-[7] These paragraphs are illustrated in figure 50, and are clearly presented in the main text.

[8]-[9] Consider figure 50: line CH is perpendicular to line AH. Therefore, the anomalistic motion of the planet at point H is along line HA, which means that this motion is not observable at this position. Moreover, it is clear from this same figure that the equation, which is the arc subtended by the line CA and the line passing through the point A and the planet, have a maximum value when the planet is at point H, i.e. when line AH is tangent to the epicycle.

[9]-[12] These paragraphs simply indicate that lines BG and CG in figure 50 are not the same. Indeed the approximation that these lines are almost equal is especially incorrect in the cases of Mars and Venus, since in both of these cases the radius of the epicycle is of a considerable length, and thus line AC is considerably longer than line AG: in the case of Venus, for example, $CA = R + e = 60 + 1;15 = 61;15$ parts, where R is the radius of the deferent, and e is the eccentricity; moreover, $CG = r = 43;10$ parts, r being the radius of the epicycle of Venus. Therefore, AG is equal to about 44 parts (in contrast to 47 parts given by Ṣadr), which is considerably smaller than CA.

[13]-[14] Again, in figure 50, the points H and G mark the points where the motion of the epicycle changes with respect to the motion of the deferent. In the case of the moon the lower part of the epicycle moves in the direction of the sequence of the signs, which means that in this part the motions of the epicycle and the deferent are additive. In the upper part, however, they are subtractive. Moreover, the maximum apparent speed of the

moon is at the epicyclic perigee, where the whole epicyclic motion is added to the deferent's motion, whereas only a component of that speed is added at other positions. In the upper part of the epicycle, the speed of the epicycle reduces that of the deferent, and the moon appears to slow down, such that its minimum speed is at the epicyclic apogee. The moon does not retrograde, since the maximum reduction in the apparent speed of the moon, resulting from the anomalistic motion at the epicyclic apogee, is always less than the forward motion of the deferent.

[15] Ṣadr states in this paragraph the basic rule through which one can determine the exact position at which the apparent motion of the planet shifts from a direct to a retrograde motion. In the following paragraphs, Ṣadr presents a simple proof for this rule, whereas both Ṭūsī and Shīrāzī refer their readers to the solution of the *Almagest* (see *Tadhkira*, 141, and *Tuḥfa*, f. 56r). Ṣadr's proof, however falls short of the elaborate proof given in the *Almagest*, and its confusion seems to reflect Ṣadr's difficulty in dealing with this complex problem.

The planets, with the exception of the moon, appear to have a retrograde motion during a portion of their movement. This is due to the fact that the angular speed of the epicycle is faster than that of the deferent. Therefore, when the component of the speed of the planet resulting from the motion of the epicycle is opposite in direction to, and greater than, the component of the speed which results from the motion of the deferent, then the planet appears to move in the direction opposite the sequence of the signs, i.e. it is retrograde. It should be noted that retrograde motion can occur only in the lower portion of the epicycle, where the deferent and the epicycle move in opposite directions.

The rule given by Ṣadr specifies the points where the above change of direction from direct to retrograde motion takes place. To illustrate this rule, consider figure 51: the large circle is the deferent, whereas the small one is the epicycle. Draw from the center of the deferent any line ABD to intersect the epicycle at points B and D. If w' is the anomalistic motion of the planet on the epicycle, and if w'' is the mean motion in longitude of the center of the epicycle on the deferent, and if the planet is at point B, which is closer to the center A of the deferent, then the rule is as follows:

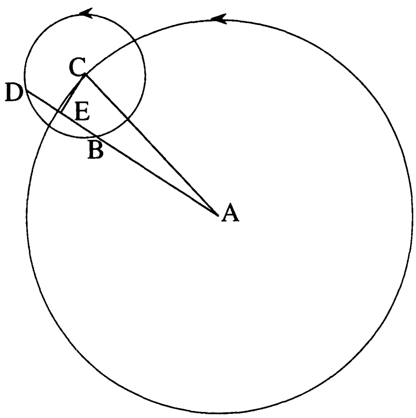


FIGURE 51

If $AB \div 1/2\ BD = w' \div w''$, then the planet appears stationary.

If $AB \div 1/2\ BD < w' \div w''$, then the planet appears to have a decelerating direct motion.

If $AB \div 1/2\ BD > w' \div w'''$, then the planet appears to retrograde.

If the point where the first condition obtains is called B', then for all positions of the planet which are closer than point B' to center A, the planet has a retrograde motion, whereas this motion is direct for all points which are farther than B' to this center.

(For an excellent proof of the above rule see Pedersen, pp. 331-338.)

[16] Ṣadr first proves the above rule for the special case in which the chord is a diameter of the epicycle, i.e. when the planet is at the epicyclic perigee. Ṣadr's proof is rather confused, and it seems to proceed as follows: consider in figure 52 the configuration where the chord BH is also the diameter of the epicycle; half the chord is the radius AB of this epicycle. Now Ṣadr considers for his illustration a case where line DE equals twice AB, which means that the radius of the deferent is three times as large as that of the epicycle. This is obviously a special case which needs not always be true. Next, Ṣadr allows the planet to move through an arc which subtends one degree angle at the center of the epicycle. The center C of the epicycle then moves through an arc which subtends the same angle at the center of the deferent, and in the direction opposite to it. Now if the motions are small enough, then for all practical purposes, point G, which is the point reached by the planet as it moves from B along the epicycle, is such that $AG = AB$. Similarly, DE is almost equal to DZ. We thus obtain two similar triangles ABG and AEZ, which means that the ratio of the bases of these triangles is equal to the ratio of the sides. Therefore, $BZ = 2\ EG$. Ṣadr then deduces that for the planet to appear stationary at position B, the epicycle

should move through twice the given angle. The assumption here is that at the limiting conditions when the motions are small, the actual motion of the planet is equivalent to the sum of the dimensions *BG* and *EZ*. So, when *DE* = 2 *AB*, for the planet to appear stationary, the epicycle should move twice as fast as the deferent. This is obviously a special case of the more general rule given above.

The propositions (figures) referred to are from the sixth book of Euclid's Elements (for the sixth and third propositions see respectively, Euclid, pp. 204, 195).

[17]-[19] Ṣadr notices correctly in these paragraphs that the above proof does not hold for large arcs of motion. Figure 53 illustrates this last point. Ṣadr adds, however, that an approximation can be justified when the arcs of motion collapse to points. In modern terminology, this means that what we are measuring are the derivatives of the motions, i.e. the velocities, rather than the motions themselves.

[20]-[21] In these two paragraphs Ṣadr gives his approximate proof for the more general case when the chord is not a diameter of the epicycle. His approach is basically to use an approximation which allows him to use the same method applied above, i.e. when the chord is a diameter: consider that in figure 54 the planet is at point *B*. Draw the circle whose diameter is the chord *BG* of the epicycle. Now the arc *BG* of the epicycle is seen from the center *A* of the deferent through an angle *BAE*, such that *AE* is the tangent drawn from point *A* to the epicycle. Moreover, if we mark *AE* such that *AE* = *AB*, then we obtain a situation similar to the first case, with *BE* approximately perpendicular to *BG*. So, for point *B* to appear stationary at the perigee of the new smaller circle, the ratio of *AB* to half *BG* should be equal to the ratio of the anomalistic motion of the planet to the motion in longitude of the center of the epicycle, which proves the above rule for the more general case.

[22]-[23] The rest of this chapter deals with the problem of finding the points where the direction of motion is reversed from direct to retrograde. Here, however, the model used employs an eccentric rather than an epicycle. Again Ṣadr attempts to prove the rules while Ṭūsī and Shīrāzī refer their readers to Ptolemy's *Almagest*. Ṣadr's proofs, however, are different from those of Ptolemy, and are vague and confusing.

To illustrate the rule in the case of an eccentric model consider figure 55: point *A* is the center of the concentric circle, and *O* is that of the eccentric one. *AO* is equal to the radius of the epicycle. The equivalence of the eccentric and epicyclic models is produced by assuming the right magnitudes and directions of motion (see the chapter on the orbs of the sun above), and as a result the position of the planet *D* on the epicycle also falls on the circumference of the eccentric. The line drawn from *A* to the planet *D* intersects the other side of the eccentric at *F*. Line *FD* is then a chord of the eccentric

circle. The rule specifies the point where the planet appears to stand still as that point where the ratio of the motion of the eccentric to the motion of the concentric is equal to the ratio $AD \div 1/2\ FD$. If the ratio of the motions is less than the ratio of the lines, then the concentric appears to decelerate, whereas if the ratio of the motions is greater, then the motion of the eccentric appears to decelerate. It should be added that when the motion of the concentric, for example, appears to slow, then the value of this motion is greater than its value at the station, and thus it will be greater than the motion of the eccentric. Thus, when the motion of the eccentric is subtracted from the motion of the concentric, the apparent motion of the concentric retains the same direction, but the apparent magnitude of this motion is reduced.

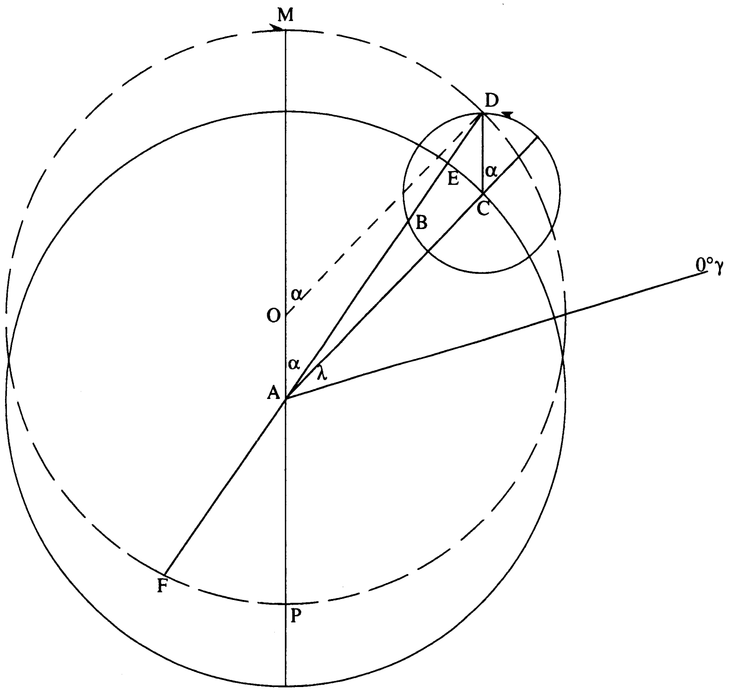


FIGURE 55

The equivalence of this last rule and the earlier one is conveniently proved in the *Almagest* (for an explanation of the equivalence, and a proof of this rule see Pedersen, pp. 339-341). Ṣadr, however, tries to prove the rule without recourse to the above equivalence, and he uses for this purpose specific numerical examples.

[24] What Ṣadr seems to be saying in this paragraph is the following (figure 55): for the case when the planet appears to stand still at the perigee, the ratio of the motion of the eccentric to the motion of the concentric is equal to $AP \div 1/2\ MP$. For any position of the planet above the perigee P, the length of the line joining the center A to the planet is larger than AP, and the length of the chord of the eccentric is less than the diameter MP. Therefore, the ratio of the distances above the perigee is greater than the ratio when the planet is at the perigee, and thus the ratio of the motions is less than the ratio of the distances, which means that the concentric only would slow for all positions above the perigee (see the rule above).

If, on the other hand, the planet appears to stop at the apogee, then using a similar analysis it can be shown that the eccentric only would slow for all positions of the planet below the apogee.

If the planet appears to stand still somewhere between the apogee and the perigee, then above the stationary point the ratio of the motions is less than the ratio of the distances, whereas below that point the ratio of the motions is greater. Therefore, when the planet is above the stationary point, the motion of the concentric retains its direction, but is slowed down by the eccentric motion, whereas below that point the motion of the eccentric retains its direction, but is slowed down by the concentric.

Now, if the direct motion refers to the concentric, then the motion is directly above the stationary point, where the motion of the concentric less that of the eccentric is still in the direction of the motion of the concentric. The motion is retrograde below that point. If, however, the direct motion refers to the eccentric, then the above is reversed.

[25]-[26] These two paragraphs follow from the above arguments. The numbers used here solve the example given earlier, namely that the eccentricity is equal to 10 parts, and the motion of the concentric is 6 degrees. Now when the motion of the eccentric is six, the stationary point is the perigee, whereas this point is the apogee when the motion of the eccentric is seven (see above). If the motion of the eccentric is between these two limits, then the above rule applies. If, however, this motion is less than five, or greater than seven, then in the first case the apparent motion of the concentric is always greater than the apparent motion of the eccentric, and there is no station or retrograde. In the second case, the apparent motion of the eccentric is always greater than that of the concentric, and the planet always appears to move in the direction of the eccentric.

[27]-[29] In these paragraphs Ṣadr repeats the proofs already presented above (see figure 56) for the case when the stationary point is at either the apogee or perigee.

(For the fifth proposition of the sixth book of Euclid's Elements see Euclid, p.202.)

[30]-[31] Ṣadr now extends his proof to cover the cases between the limiting conditions at the apogee and the perigee. He does this, however, by simply stating that the chord can always be considered to be a diameter of a smaller circle. This is clearly with reference to the method which he used in the case of the epicyclic model. Ṣadr rightly notices, however, that his method has a flaw, namely that the prove which he uses requires that the radius of the eccentric be 60 parts, whereas the use of a smaller circle to encompass the chord would produce an eccentric whose radius is less than sixty. No solution is given to this problem.

It should be noted, however, that the above problem arises only when Ṣadr's cryptic method is used, whereas no such problem arises what so ever when using Ptolemy's exact proofs.

[32] Retrograde motion, as mentioned above, occurs only at the perigees of the wandering planets. Ṣadr, however, claims that he covers in his exposition the theoretical possibility of having retrograde motions at apogees.

[33]-[35] The two quotations cited here are indeed present in different versions of the *Tadhkira*, indicating the possibility of there having existed two different versions of the original text (for the different variants see *Tadhkira*, pp. 137-41).

Ṣadr rightly notices that the two different statements have different implications. If we assume the eccentricity to be e, the radius of the epicycle r, and the radius of the eccentric equals the radius of the concentric, both being R, then the first statement simply means that $R/e = R/r$. This means that the epicyclic and eccentric models are equivalent, and the corresponding angles of motion seen at the center of the world are equal in both models. The second statement, however, is as follows: $(R-e)/R = (R-r)/r$. Now if $e = r$, then $R = r$, which means that the corresponding arcs of motion are equal.

CHAPTER 10

[1] This chapter corresponds to two similar chapters in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, pp. 223-9, and *Tuḥfa*, 181r-183r). All the above chapters are concise and rather summarized versions of Book V of the *Almagest*.

[2] The basic principle of the parallax is quite simple: let point G in figure 57 be the center of the earth, point O be the locality of an observer on its surface, and M be the location of the moon. The outer circle with center G is the altitude circle marked on the celestial sphere. If we join lines OM and GM to intersect the latitude circle at V and T respectively, then V corresponds to the apparent position of the moon, whereas T corresponds to the true position. It is clear from figure 57, that the true position of the moon is different from the apparent one, and that the difference between the two positions is a function of both the radius of the earth and the distance between the earth and the moon. Arc TV is called the arc of parallax, and angle OMG is the parallax angle.

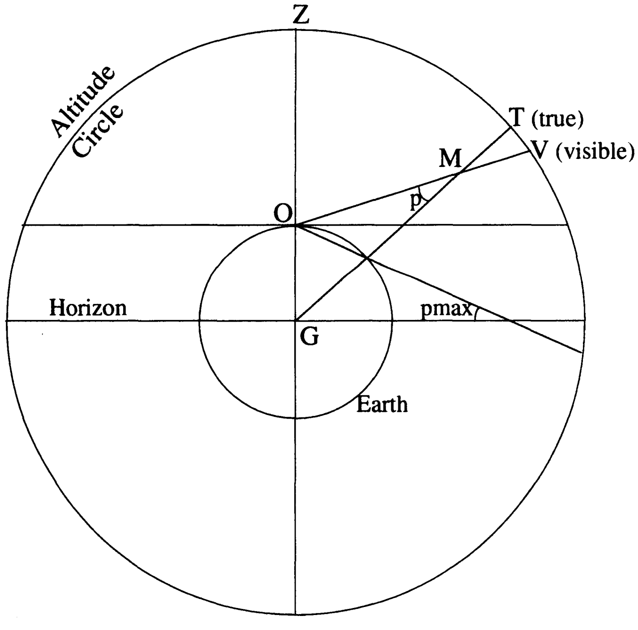


FIGURE 57

Theoretically, all planets could have a parallax. This parallax, however, becomes smaller, and hence harder to detect, when the planet in question is too far from the earth. This is why Ṣadr states that the parallax is only detectable in the case of the moon, where the size of the earth's radius is not insignificant with respect to the distance between the earth and the moon.

The present chapter is descriptive, and no calculation is made for actual parallaxes corresponding to actual positions of the moon (for a survey of the parallax theories in Islamic astronomy in which extensive calculations were used see Kennedy, 1983, pp. 164-184).

[3] It is clear from figure 57 that when lines *GM* and *OM* coincide, i.e., when *M* falls along line *GOZ*, then the parallax is zero. The apparent and true positions of the moon is then at the zenith.

In figure 57, one can show that the maximum parallax occurs when the moon is at the horizon.

Also in figure 57, the visible part of the orb of the moon is less than the hidden part, because the radius of the earth is not negligible with respect to the distance between the earth and the moon.

[4] Figure 58 illustrates this paragraph: Arc *TV* is the arc of parallax, and it is measured along the altitude circle passing through the zenith of the observer. It is obvious that this arc has a longitudinal component, and another component in latitude; these are respectively arcs *QV* and *QT*.

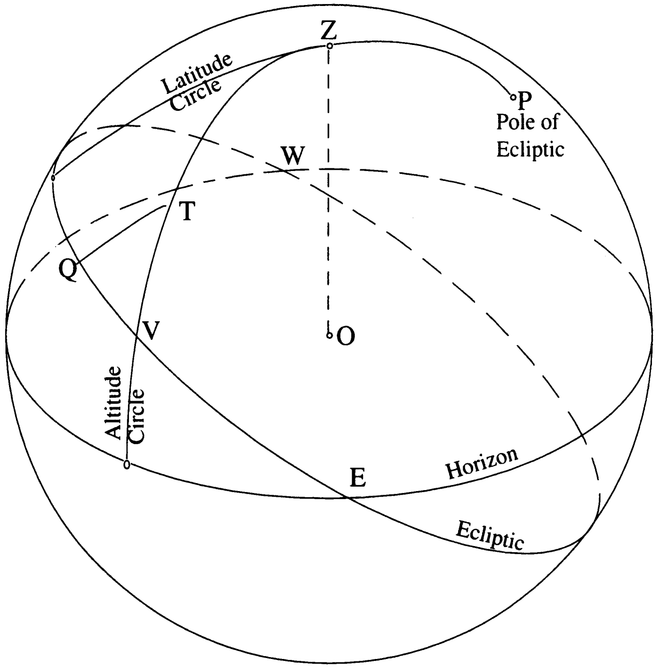


FIGURE 58

Now if the moon falls on the plane of the latitude circle passing through P and Z, then there is clearly no longitudinal component for the parallax. If the moon falls east of the latitude circle, then the longitude of the apparent position is greater than that of the true one, assuming that the longitude is measured from the west to the east. In figure 58 this means that arc $WV >$ arc WQ. The reverse is true if the moon falls to the west of the latitude circle.

[5]-[11] It is clear from the above paragraph that the longitudinal variation of the parallax is a function of the position of the moon with respect to the latitude circle. On the other hand, the variation of the latitude component is a function of the position of the moon with respect to the ecliptic, and the position of the ecliptic with respect to the zenith. The cases discussed in the remaining paragraphs of this chapter are simple examples of the dependence of parallax on the above two variables.

CHAPTER 11

[1] This chapter corresponds to two chapters in the *Tadhkira* and the *Tuḥfa* entitled "on the variation in the moon's illumination and on lunar and solar eclipses" (see *Tadhkira*, pp. 229-39, and *Tuḥfa*, f. 183r-198r). The first of these chapters is quite similar to Ṣadr's, both in size and scope. The chapter in the *Tuḥfa*, however, is the only one which is comparable to the corresponding elaborate section in the *Almagest* (see Pedersen, VI, pp. 275-320).

[2] The use of the term "almost" in this paragraph refers to the fact that the sun is larger than the moon, thus the part of the moon which receives the light of the sun is slightly larger than its half. Similarly, less than half the surface of the moon is apparent to the observer.

[3]-[6] These three paragraphs describe the phases of the moon: the body of the moon is divided by two imaginary circles, the first of which separates its bright side from its dark side, whereas the second separates the part of the moon which faces the earth from the part which is not visible to it. The intersection between these two circles determines the shape of the bright part of the moon which is seen by an observer on the earth.

In figure 59 the shaded area corresponds to the dark part of the moon. figures 59.VI, and 59.VIII correspond to the first and second examples of paragraph [5] respectively.

[7] Figure 60 illustrates this paragraph. The second light referred to here is the one which results from the reflection of the rays of light coming from the sun as they pass through the earth's atmosphere. During the waning phase of the moon (*muḥāq*), the moon is between the sun and earth; thus, the angle traced by a ray of light as it travels from the sun to the earth's atmosphere, and then is reflected to the moon, is an acute angle. On the other hand, if the moon is eclipsed by the earth, and hence is in opposition with the sun, then the above angle of reflection is an obtuse angle. Ṣadr then adds that the obtuse angle is closer to a straight line, and the brightest light is that which travels along straight lines. Therefore, the light which is reflected during the waning of the moon is negligible.

[8]-[9] The following paragraphs deal with the lunar and solar eclipses, their locations, durations, and intervals between them. (For an excellent discussion of Ptolemy's determination of the sizes of the sun and the moon, the size of the shadow circle, the positions of the solar and lunar eclipses, and the intervals between them see HAMA, 104-105, and 125-129; also see Pedersen, pp. 227-230).

In the following commentary only some of the problematic points in the present text are discussed, while the above references can be consulted for the general solution of the problems of this chapter.

Having mentioned the evidence for the fact that the shadow beam has a conical shape, Ṣadr points out that some maintain that the tip of this cone may reach Venus when the sun is at its farthest distance from the earth. It should be pointed out that while the evidence for the first fact is observational, the second statement is only derivable by calculation, since Venus is too far for any shadow to be actually seen.

[10]-[11] The lunar eclipse occurs if the moon passes through the shadow circle. Now since this circle is always larger than the apparent size of the shadow circle, different kinds of lunar eclipses may therefore occur. The moon may pass fully through the shadow circle, or only a part of it may pass through. In the first case a total eclipse results, while in the second case the eclipse is partial. To determine the positions at which an eclipses takes place, it suffices to determine the position of the disc of the moon with respect to the shadow circle.

Point *O* in figure 61 is the center of the shadow circle, and it falls in the plane of the ecliptic. Point *C* is the center of the lunar disk. *OC* is the altitude of the center of the moon above the plane of the ecliptic. The problem is thus reduced to determining the position and kind of lunar eclipse as a function of the latitude *OC*. One still needs, however, to determine the apparent sizes of the shadow circle and the moon.

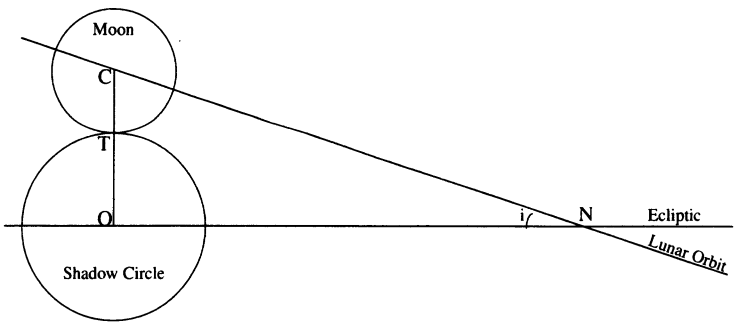


FIGURE 61

The ratio of the diameter of the shadow circle to the diameter of the moon is found to be almost constant. Obviously, the basis for this last result is the observational data which was used by Ptolemy, but Ṣadr's recourse to Ptolemy's parameters is implicit.

Ṣadr, however, repeats a mistake which appears in the *Tuḥfa*. Both Ṣadr and Shīrāzī maintain that the ratio *OT*/*TC* in figure 61 is equal to one and

three fifths (see *Tuḥfa*, f. 189v). However, Ptolemy, as well as Ṭūsī (see *Tadhkira*, pp. 233-5), note that, at the minimum and maximum distances of the moon, the radius of the shadow circle is approximately equal to two and three fifths the apparent radius of the moon. Furthermore, the above divergence is definitely a mistake on the part of Shīrāzī and Ṣadr, rather than a modification of Ptolemy's figures, because later parameters which are deduced from the present one agree in all four sources(see paragraph [16] below).

The example used by Ṣadr employs the above erroneous ratio, but it still serves the purpose of illustrating the possible kinds of lunar eclipses, and the conditions for their occurrence. It should be added that Ṣadr notices latter on in his commentary that the value which he quotes for the above ratio does not correspond to the later calculations (see *A*, f. 51v), but he still does nothing to correct this mistake.

[12] This paragraph simply refers to a specific unit which is used to measure the moon. If the unit "digit" is used without further qualification, then it refers to the diameter of the moon, whereas it refers to the whole body of the moon when used together with a qualifying adjective, possibly the "solid digits".

[13]-[15] These paragraphs discuss the solar eclipses. The values of the apparent radii of the moon and the sun which are quoted here by Ṣadr, and which are naturally used in the *Tadhkira* and the *Tuḥfa*, are not the same figures used by Ptolemy. Moreover, while Ptolemy's observations include only one apparent diameter for the sun, the later sources have maximum and minimum apparent diameters (for the corresponding figures see HAMA, p. 106; also see *Tadhkira*, p. 237, and *Tuḥfa*, f. 193v).

Solar eclipses are obviously affected by parallax, because the apparent and true positions of the moon are, in general, not the same. Now without further elaboration, Ṣadr proceeds to discuss the above problem as a function of the adjusted latitude of the center of the moon, i.e., the apparent latitude after including the influence of parallax. The basic point is that if the moon creeps in between the sun and earth, then it will hide part or all of what we see of the sun.

Consider that in figure 62 the apparent radius of the moon is r while that of the sun is r', and let S be the center of the sun, while M is the center of the moon. Point S clearly falls on the ecliptic, and SM is the adjusted latitude of the moon. The limiting case where no solar eclipse would take place is when $SM > r + r'$ (figure 62.I). The rest of the cases discussed are illustrated in figure 62.I-VII, and are self explanatory (for more discussion see HAMA, pp. 125-129, and Pedersen, 227-230).

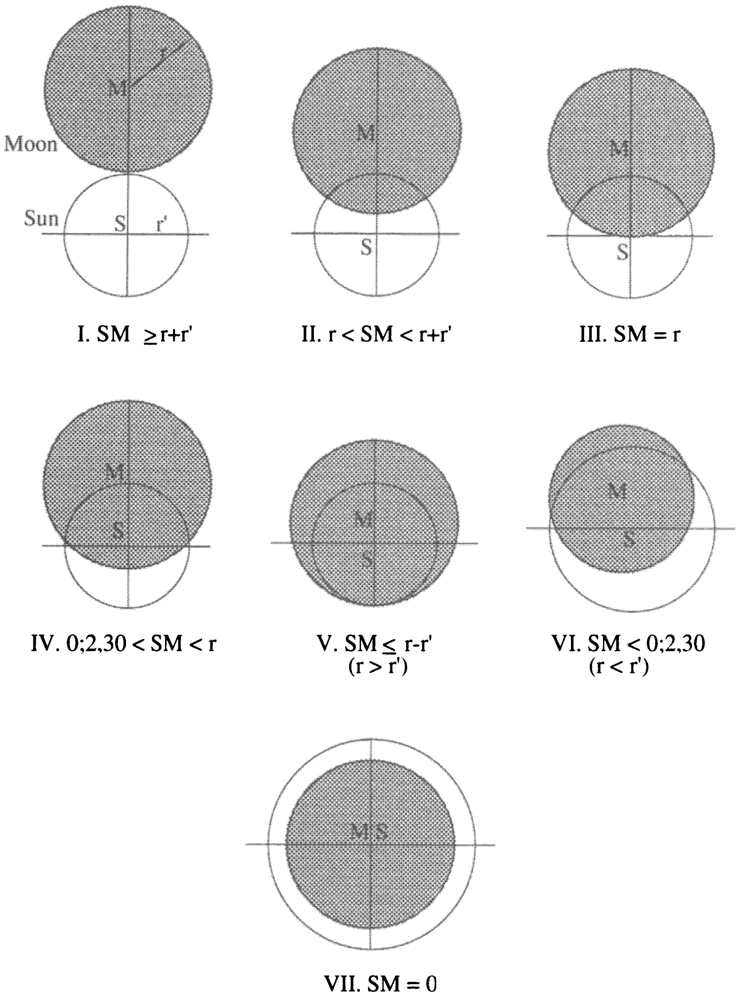


FIGURE 62

The largest limits for solar eclipses are when the moon has its largest apparent size, and the sun has its smallest one. At these limits $r = 36/2$ minutes, and $r' = 31/2$ minutes. Therefore, $r - r' = 0;2,30°$, hence the limiting figure used by Ṣadr in his illustrations.

[16] Having described the general conditions at which a lunar eclipse takes place, Ṣadr moves on to specify the distance of the center of the moon away from the node, beyond which no eclipse can occur. In figure 61, point N is the node, C the center of the moon, and O the center of the shadow circle. The maximum latitude OC beyond which the moon does not enter in

the shadow circle is equal to the sum of the apparent radius of the shadow circle and that of the moon. Again, the largest limit for eclipse obtains when the apparent size of the moon is largest, i.e. when the moon is at the perigee. Now if we use the Ptolemaic ratio 2 and 3/5 for OT/TC, then for TC = 18 minutes, we obtain OC = 1;4,48°. Moreover, the angle CNO equals the inclination of the lunar orbit with respect to the plane of the ecliptic, i.e. 5°. Therefore, $NC = OC/\sin CNO$ = 12;23°, which is close to the 12;12 value obtained by Ptolemy (for the value in the *Almagest* see HAMA, p. 125, and Pedersen, p. 229; also for the corresponding figure of 12 degrees see *Tadhkira*, p. 233-5, and *Tuḥfa*, f. 195r).

If, however, we use the ratio 1 and 3/5, which is erroneously quoted by Ṣadr, then we would get NC = 8;57, which is far below the lunar eclipse limit which Ṣadr uses.

Therefore, it seems that a copying mistake may have been incorporated into the text of the *Tadhkira*, and thence it to the *Tuḥfa*, and through both to the present work.

[17] The limit of a solar eclipse is further affected by the parallax. Therefore, those limits are also a function of the positions on earth for which they are calculated. Now Ptolemy chooses two arbitrary localities and assumes they are the boundary or extremal positions. He then calculates the limits of the solar eclipses at these two positions which are south and north of the ecliptic, and comes out with 8;22 and 17;41 degrees respectively (see HAMA, p. 126). These figures, as Neugebauer shows, are as arbitrary as the positions which were chosen by Ptolemy, and "could not represent the extremal conditions he was looking for" (see HAMA, p. 129).

The corresponding values given by Ṣadr are 7 and 18 degrees, and they are the same figures given in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, f. 57v-58r, and *Tuḥfa*, f. 195v). It is not clear to me, however, whether these values are simple refinements of the Ptolemaic ones, or whether they are based on a different set of extremal conditions.

[18]-[21] Having determined the limits of eclipses, it becomes a matter of simple calculation to determine the intervals between successive eclipses. An eclipse recurs at the next point where the moon falls within the limits given above.

The following paragraphs are simple and self explanatory. (For an elaborate solution of the above problem see HAMA, 129-134; also see Pedersen, 230-231).

[22] The moon moves from the west to the east, thus its eastern edge leads into the shadow circle, and is the first to leave it. Therefore, the beginning of darkening and clearing in a lunar eclipse is from the east side of the moon. The opposite argument applies for the solar eclipse.

CHAPTER 12

[1] This chapter discusses the planetary visibility, and the conditions which govern it. Ptolemy addresses this question in the last three chapters of the *Almagest*, but mainly toward the end of chapter XIII (see *Almagest*, XIII, pp. 636-647).

Ṣadr's approach to this question is descriptive and does not employ any of the calculations included in the *Almagest*. This is more in line with the similar approaches in the *Tadhkira*, and the *Tuḥfa* (see *Tadhkira*, p. 241-3, and *Tuḥfa*, f. 199r-204r).

[2] The visibility of a planet is a function of the latitude of this planet, the latitude of the locality of the observer, and the portion of the ecliptic which is rising or setting at the time in question. The elongation between the sun and the planet is a function of these variables, and a minimum elongation is required so that, upon the arrival of the sun at a certain depression below the horizon, the planet becomes visible. (for Ptolemy's solution of this problem see HAMA, pp. 230-261, and Pedersen, pp. 386-388; on "Planetary Visibility in Islamic Astronomy" see Kennedy, 1983, pp. 144-150).

In the case of the superior planets the situation is rather simple (figure 63): when the planet retrogrades, the sun and the planet are in opposite directions with respect to the earth. Therefore, the retrograde motion of the planet is completely visible, since at no point during this motion would the planet fall within the glare of the sun. Now the sun is faster than the superior planets (see the chapter on the superior planets above); the planet thus has its last visibility just before setting, i.e. as an evening star. The planet then becomes invisible, during which period it is overtaken by the sun, and it later reaches its first visibility just before rising, i.e. as a morning star.

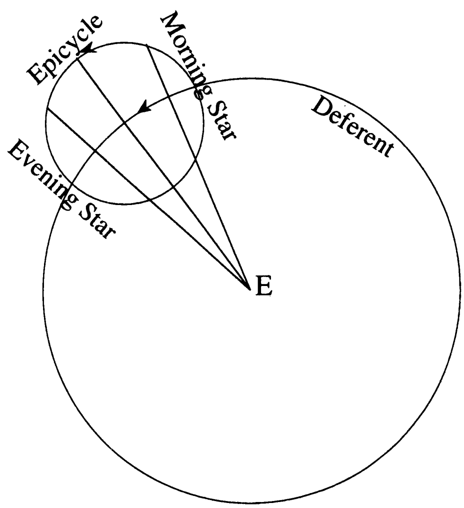


FIGURE 63

[3] The case of the inferior planets is slightly more complicated than the superior planets. The main difference is that the inferior planets become invisible due to the brightness of the sun in two different situations, namely during both direct and retrograde motions. Moreover, the inferior planets move faster than the sun. Therefore, during direct motion, an inferior planet has its first visibility as an evening star, which is followed by its last visibility. The planet then becomes invisible, until it reaches the zone of retrograde motion, where it has a first visibility as a morning star.

[4]-[8] In the following sections Ṣadr discusses some specific characteristics of Venus and Mercury. The points raised in these sections correspond with, and also respond to, similar remarks made in the *Tuḥfa* (see *Tuḥfa*, f. 201r-202r).

The arc of invisibility near the inferior conjunction of the planet with the sun is smaller than the corresponding arc near the superior conjunction. Therefore, the planet's motion in latitude brings the planet closer to the cone of invisibility during inferior conjunction, and influences the duration of this invisibility (for a brief and clear explanation of this point see HAMA, pp. 1090).

CHAPTER 13

[1]-[5] Despite some similarity to Book II of the *Almagest* (see Pedersen, II, pp. 75-132), the following chapters display considerable differences, bearing witness to the original character developed by Arabic astronomy over the centuries.

These sections proceed to discuss astronomical questions related to the earth, according to the scheme set forth at the beginning of this work, and following the general layout of the *Tuḥfa* and the *Tadhkira*. (For the general arrangement of such works see Livingston.)

Of the corresponding sections, those in the *Tadhkira* are the closest to this chapter (see *Tadhkira*, p. 245-53, and *Tuḥfa*, f. 204v-221v).

The reference to Divine Providence is indeed found in the *Tadhkira* (see *Tadhkira*, p. 249), but this reference comes at the conclusion of an elaborate exposition of the different possible explanations of the natural order of the earth. Needless to say, Ṣadr excludes those explanations from his introduction.

[6]-[7] For the most part, these tables duplicate the corresponding numbers of the *Tadhkira* (see *Tadhkira*, pp. 251-3, and *Tuḥfa*, f. 220r-220v).

Many of the numbers appearing in the manuscripts were either distorted or were completely omitted. Wide divergences from the corresponding tables of the *Tadhkira*, where most of the other entries are exactly the same, were taken as evidence for such distortion, and were corrected accordingly.

Climates are zones of the northern hemisphere which are parallel to the equator (for a definition of climates, and for a derivation of the relation between the latitude of a climate and the hours of the longest day see Dallal, pp. 3-18). Most of the inhabited land falls within the seven climates specified in the first table. The second table gives a brief specification of the areas not covered in the first.

CHAPTER 14

[1] Again this chapter is similar to the corresponding chapters in the *Tadhkira* and the *Tuḥfa*, with greater affinity to the former. The main divergence in Ṣadr's work, however, is that it includes several sections which in the other two works are divided into several chapters (see *Tadhkira*, pp. 255-81, and *Tuḥfa*, f. 221v-237v).

[2]-[4] The first part of this chapter deals with the conditions at the equator, where the latitude of the locality is zero (for the corresponding sections see *Tadhkira*, pp. 255-9, and *Tuḥfa*, f. 221v-224v).

Ṣadr proceeds to explain the characteristics of localities at the equator without defining his use of technical terms. This is partly because many of these terms have already been defined in the beginning of his work (for a short introduction to astronomical concepts, and systems of coordinates see HAMA, pp. 1077-1080).

Figure 64 illustrates the general situation of a locality at the equator. The plane of the horizon circle is tangent to the surface of the earth at the locality, which means that the horizon is perpendicular to the equator, and the former passes through the two poles of the latter. Now since the day circles are parallel to the equator, the horizon bisects these circles, and their corresponding portions on either side of the horizon are equal. Thus, the day is always equal to the night.

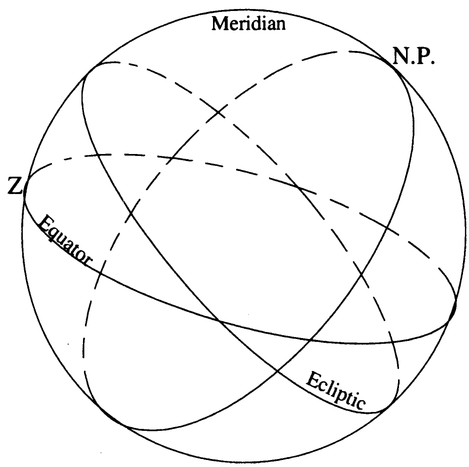


FIGURE 64

Now a star on the celestial sphere has two motions. The first is the daily motion around the pole of the equator, while the second is a slower motion in the opposite direction, around the pole of the ecliptic. So if this star moves by the second motion through a certain arc, then the new position of the star will have an ascension different from that of the original position. Therefore, the variation in the times of visibility and invisibility is due to the second motion itself, and not to a variation in this motion.

(for the quotation from the *Tadhkira* see p. 255.)

[5]-[8] Ṣadr discusses in these paragraphs the special case when the locality falls on the equator, and when the zenith of the locality falls on one of the equinoctial points (see figure 65). It is clear from the figure that the horizon circle passes through the pole of the ecliptic, and that the ecliptic circle passes through the pole of the horizon circle, which means that the two circles are perpendicular.

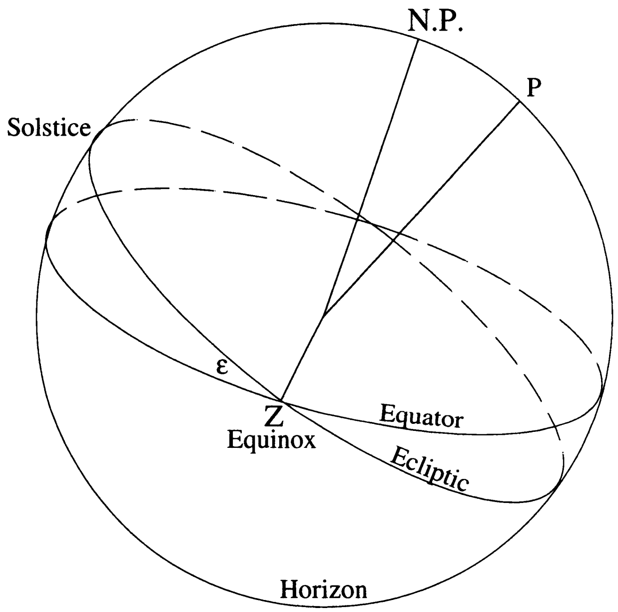


FIGURE 65

Now if the sun passes over the zenith twice, i.e. at the two equinoctial points, then there are two summers during one year. Moreover, the sun is at its farthest distance from the zenith at the two solstices, which means that there are two winters during this year. Therefore, there are eight seasons for the special case considered above.

The rising amplitude of a point is the arc on the horizon which falls between the rising point of the point and the equator. Now since the horizon circle in the above case is perpendicular to the equator, therefore, the rising amplitude is an arc on the declination circle between the point in question and the equator. The eastern amplitude and the declination are thus equal.

The discussion concerning the alleged temperate climate at the above locality is in reference to the *Tadhkira*. The arguments to which Ṣadr responds are quotations from Ibn Sīna and Rāzī consecutively (see *Tadhkira*, pp. 257-9).

[9] This astrological reference to the concept of temperament is quoted from the *Tadhkira* (see p. 259).

[10] Paragraphs [10]-[15] are subsumed under separate chapters in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, pp. 259-63, and *Tuḥfa*, f. 224v-230v).

These paragraphs are not very clear, and some assumptions had to be made to make sense of them.

The rotation of the ecliptic observed from a locality which does not fall on the equator is wobbly because of the combined effect of its daily and yearly motion.

In a case where the star is on the side of the visible pole (see figure 66), and the altitude *AS* of the star is less than or equal to the altitude *AN* of the pole, the star is always visible, since its day circle falls completely above the horizon. The second condition in question, namely that a certain distance of the star from some point is greater than *AN*, must refer to the arc *NS'*, since if *NS'* > *NA*, then part of the day circle of the star falls below the horizon, and the star is invisible during part of its rotation. It is clear from figure 66 that the invisible part is smaller than the visible one.

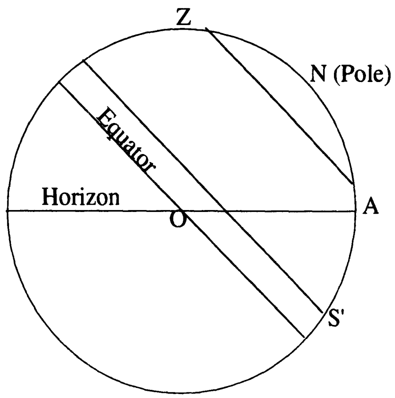


FIGURE 66

[12]-[15] In these paragraphs Ṣadr defines the equation of daylight and the methods of finding it (for the corresponding sections see *Tadhkira*, p. 259-63, and *Tuḥfa*, f. 225v-227r).

The wording of these sections is not clear; what Ṣadr seems to be saying is the following: consider a star S such that the day circle passing through it intersects the horizon at point A (see figure 67). Point A is the rising point of this star. Now if we draw through the north pole N a declination circle NA to intersect the day circle at A and the equator at H, and if the horizon east point is E, then a spherical right angle triangle EHA will be obtained. In this triangle arc EA is the rising amplitude of the star, arc AH its declination, and arc EH half the equation of day light of that star. It is clear from the same figure that if we draw a declination circle through point A', which is the other intersection between the day circle and the horizon, then a western triangle equal to the eastern one is obtained. It can also be seen that if the star is on the side of the visible pole, then the triangle will be below the horizon, and conversely for the case when the star is on the side of the invisible pole.

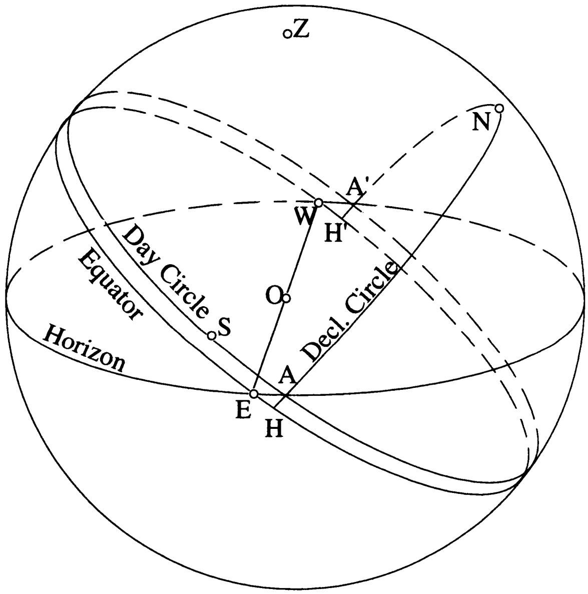


FIGURE 67

Alternatively, one could draw one declination circle through N perpendicular to the equator at its east and west points (see figure 68). Arc AH of the resultant triangle EHA will be the equation of day light.

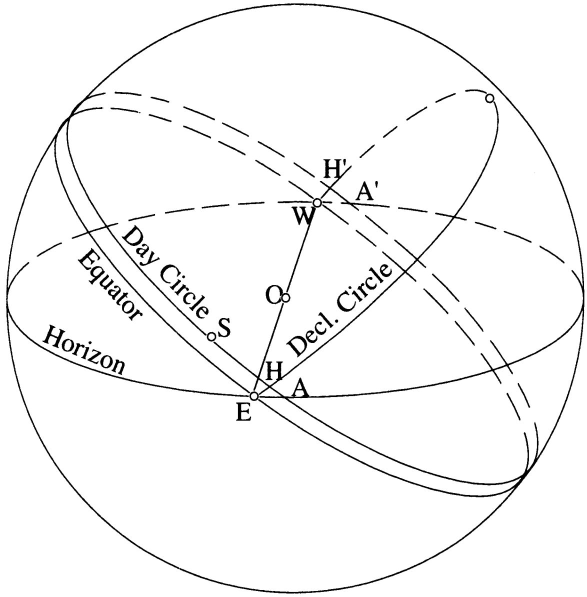


FIGURE 68

Ṣadr gives the following proof for the above: For a locality on the equator, the horizon of that locality is its declination circle. Points *E* and *H* thus rise and set together with respect to the new horizon , and the same point *H* can then be used to mark the rising of the star *S*.

(For a modern derivation of the equation of day light see Bīrūnī, vol. 2, pp. 88-89).

[16] Figure 69 illustrates this paragraph: if the day circle has a declination equal to the latitude of the locality, then it will pass through point *Z*, the zenith of the locality. If the declination is greater than the latitude, then the day circle will not pass through the zenith, and it will not intersect the prime vertical. If, however, the day circle has a declination less than the latitude, then it intersects the prime vertical at two points: point *I*, and the point immediately behind it in the plane of the figure (for the corresponding sections see *Tadhkira*, pp. 261-3, and *Tuḥfa*, f. 225v).

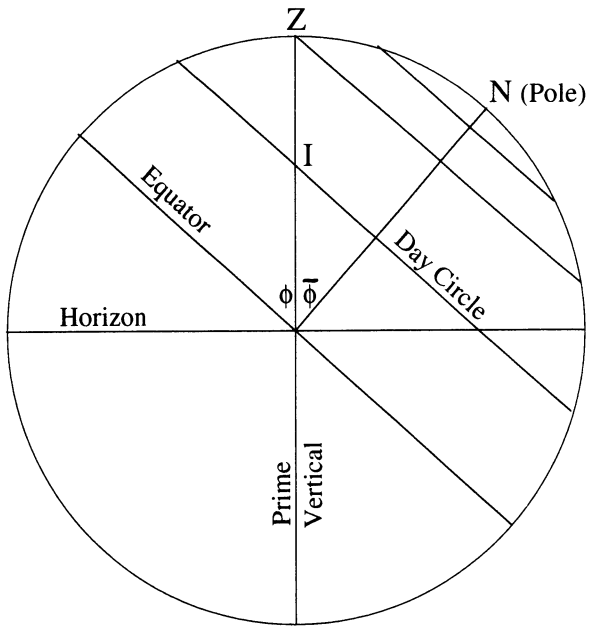


FIGURE 69

[17] The remaining paragraphs of this chapter deal with the characteristics of the localities which have latitudes, i.e. those which are not on the equator. These characteristics include, among other things, the description of the passage of the sun, the appearance of the ecliptic, and the rising and setting of the sun and stars at the specific localities in question (for the corresponding sections see *Tadhkira*, pp. 263-81, and *Tuḥfa*, f. 224v-234v).

Figure 70 illustrates this paragraph. Arc AZ is equal to the latitude of the locality, and it is less than arc AT, the obliquity of the ecliptic. The declinations of the day circles which pass through points S and S' on the ecliptic are equal to the latitude of the locality. These two circles pass through the zenith of the locality, and so does the sun. It is also clear from figure 70 that the sun can cast shadows from point O which are either to the south or to the north of the prime vertical OZ, depending on the position of the ecliptic, and on the location of the sun on it.

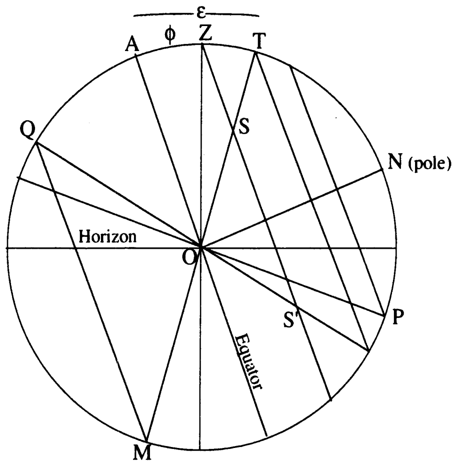


FIGURE 70

[18] Figure 71 illustrates this paragraph. The latitude of the locality is equal to the obliquity of the ecliptic. Therefore, the extremal positions of the ecliptic are positions *ZM* and *QR*. This means that the sun passes only once through the zenith. It also means that one of the poles of the ecliptic travels along the circle *PH*, and is thus permanently visible, while the other one is permanently invisible. Moreover, when the ecliptic is at the position *ZM*, that is when the solsticial point is at the zenith, the two poles of the ecliptic touch the horizon.

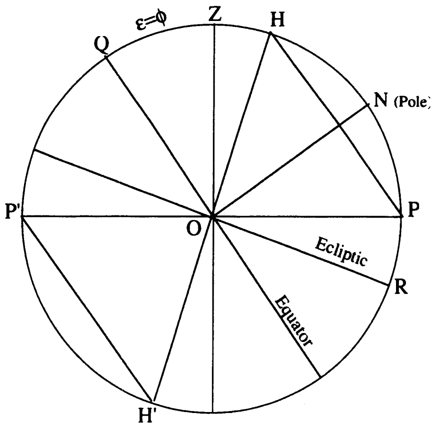


FIGURE 71

On the other hand, the shadows cast in the above locality at midday always fall on one side, since the midday sun always falls on one side of the meridian circle, namely on arc ZQ, and its shadow is thus north of the line ZM.

[19] When the latitude of the locality is equal to or less than the obliquity of the ecliptic, then a permanently visible star is one whose day circle intersects the meridian between points P and H (figure 71). This means that the distance between the pole of the world and the star is equal to or less than the altitude of this pole above the horizon. Now a star falling on arc PH may move outside this arc as a result of the second motion, while a star outside it may be brought inside. In the first case the star has a rising and a setting, and is not permanently visible any more, while in the second case the star becomes permanently visible. The same applies for a permanently invisible star.

[20] In figure 72 the distance SP between the Star S and the pole of the ecliptic P is equal to the complement of the latitude of this star above the ecliptic. In other words, $QS + SP = 90°$. The difference between the latitude of the locality and the obliquity of the ecliptic is $QZ = KP$ = the altitude of the lower position of the pole of the ecliptic. Now if $PS \leq PK$, then the star does not rise or set as a result of the second motion, simply because the rotation of this star around the pole of the ecliptic is always above the horizon. If $PS > PK$, then the star has a rising and a setting.

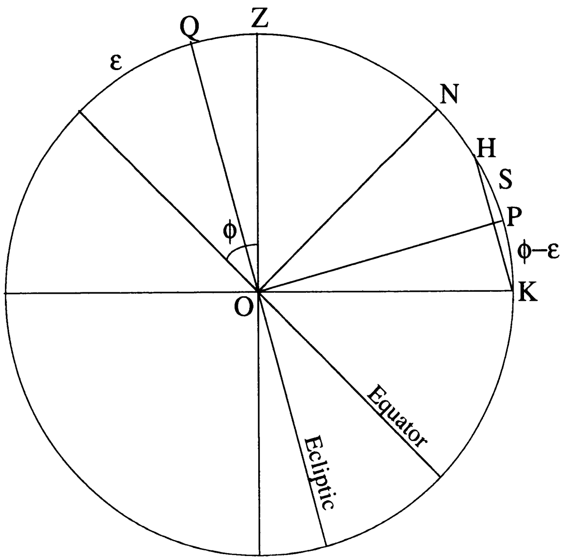


FIGURE 72

[21]-[22] In figure 73, the maximum altitude of the sun is arc *MR*, which is equal to the sum of arcs *MQ* and *QR*. This altitude is thus equal to the complement of the latitude of the locality plus the obliquity of the ecliptic. The minimum latitude equals the difference of these two arcs.

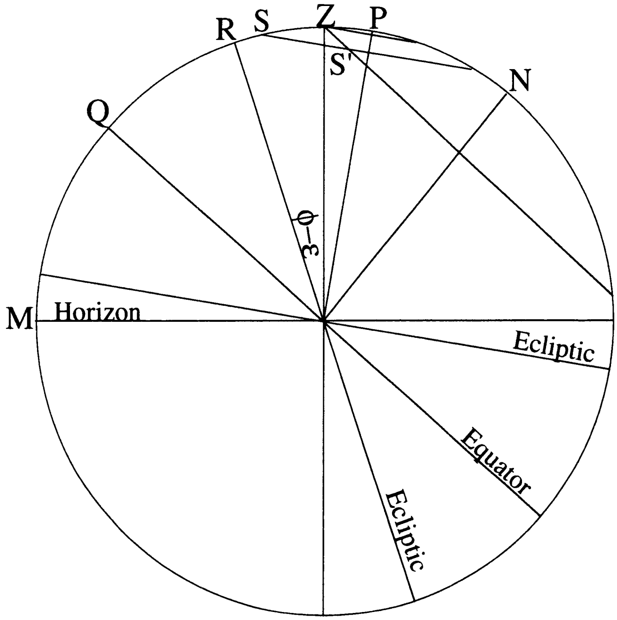


FIGURE 73

Also in figure 73, arc *RZ* is equal to the latitude of the locality less the obliquity of the ecliptic. Now if the latitude of a planet *S* above the ecliptic, namely arc *RS*, is greater than *RZ*, then the day circle of that planet does not pass through the zenith of the locality. If the two arcs are equal then the day circle of the planet passes once through the zenith. Finally, if $RS < RZ$, then the path of *S* around the pole of the ecliptic intersects the prime vertical at two points. This means that there are two points on this path through which a day circle of the star *S* passes through the zenith; these two points are *S'* and the point immediately below it in the plane of figure 73.

[23] If the equation of day light is *e*, then this equation can be found by the formula: $\sin e = \tan \phi \times \tan \delta$, where ϕ is the latitude of the locality, and δ is the declination of the sun for that day (for a derivation of this formula see HAMA, p. 36). It is thus clear that, for a fixed declination, as the latitude of the locality increases, the equation of day light will also increase. A similar argument applies for the eastern amplitude of the locality.

Figure 74 illustrates this paragraph. The latitude of the first locality is equal to QZ, and it is less than the latitude $Q'Z$ of the second locality. The equation of day light is arc EH, while the rising amplitude is arc EK. It is clear from this figure that for a latitude $Q'Z > QZ$ we get $EH' > EH$ and $EK' > EK$.

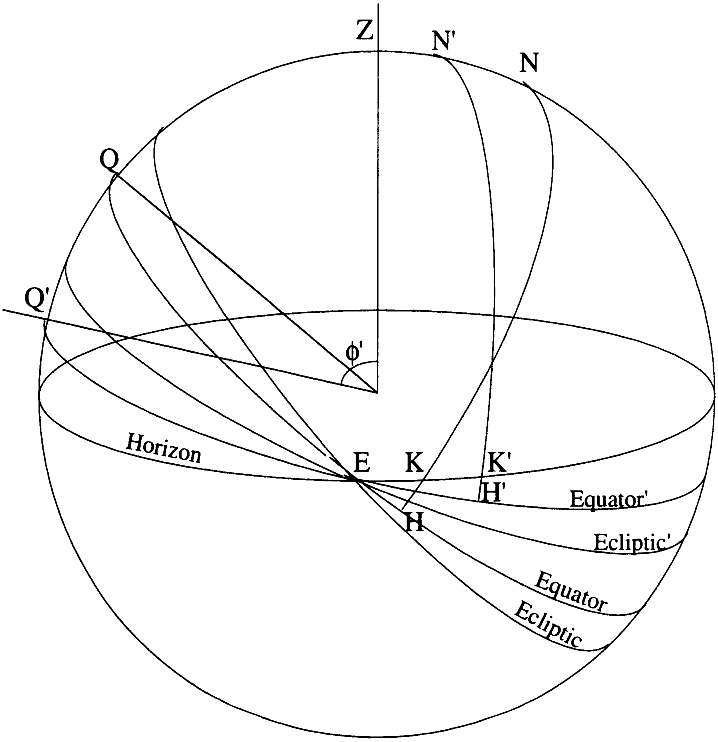


FIGURE 74

[24] Figure 75 illustrates the case in which the latitude of the locality is equal to the complement of the obliquity of the ecliptic. In this case the equator is inclined with respect to the horizon at an angle equal to the obliquity of the ecliptic, and one of the extremal positions of the ecliptic is at the horizon. Moreover, the pole of the ecliptic rotates on circle PP'. Now if the beginning of Cancer falls on the north point H of the horizon when the pole of the ecliptic coincides with the zenith of the locality, then the beginning of Capricorn falls on the south point K of the horizon. As the pole of the ecliptic moves to its lowest position at P, the beginning of Cancer reaches its highest point L above the south point of the horizon, while the beginning of Capricorn reaches its lowest point M below the north point of

the horizon. Thus, in the direction of the sequence of the signs, the part of the ecliptic between the beginning of Cancer and the beginning of Capricorn rises with every rotation of the equator, whereas the other part of the ecliptic will never rise above the horizon.

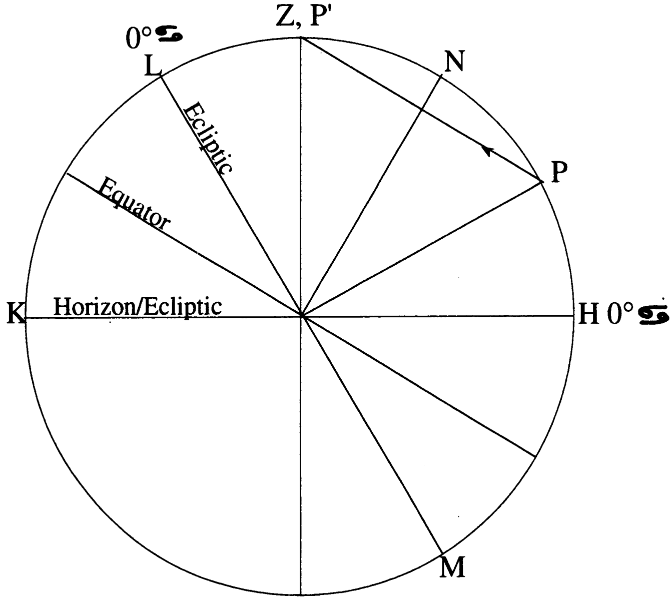


FIGURE 75

[25]-[31] Figure 76 illustrate the case in which the latitude of the locality is greater than the complement of the obliquity of the ecliptic, and less than ninety degrees. Now those parts of the ecliptic which have a minimum declination north of the equator, such that this declination is equal to or greater than the complement of the latitude of the locality, are always above the horizon, and are consequently permanently visible. The parts of the ecliptic which have the same declination south of the equator are permanently invisible.

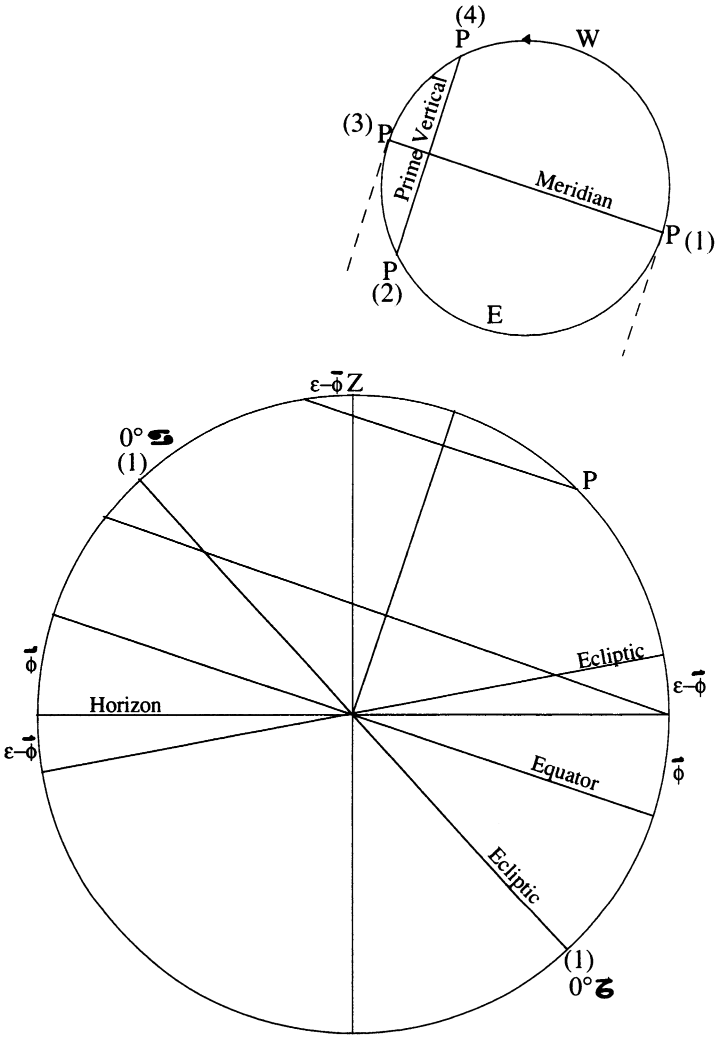


FIGURE 76

Figure 76 also shows the path of the pole of the ecliptic as it rotates around the pole of the world. The signs of the ecliptic which are neither permanently visible nor invisible rise and set according to the position of the pole of the ecliptic along its path. This path is clearly divided by the meridian circle and the prime vertical into four parts. The two northern parts are equal, and so are the two southern parts. The first two parts are greater than the second two.

Ṣadr considers an example where the latitude of the locality is 70°, in which case Gemini and Cancer are permanently visible, and Sagittarius and Capricorn are permanently invisible. Two of the remaining eight signs thus rise as the pole of the ecliptic moves through eight of the four sections of its path which are specified above. It is thus clear that the time for the rising for four of these signs is greater than the corresponding time for the other four, since the pole of the ecliptic covers unequal arcs during the motion of each of the above two sets of signs. When the pole of the ecliptic is at position (1) (figure 76), the configuration of the signs is as in figure 77. As the pole of the ecliptic moves to position (2), the configuration of the signs becomes as in figure 78. At this last position, the pole of the ecliptic is inclined to the east of the line *OZ*, and the eastern part of the ecliptic sets below the horizon.

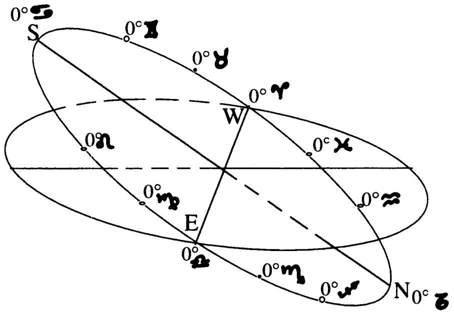


FIGURE 77

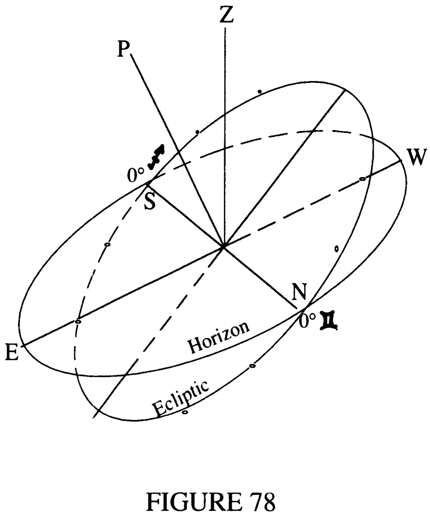


FIGURE 78

The rising and setting of the signs of the ecliptic results from its two motions: the first of these two motions is the rotation of the ecliptic around its own axis, and the rising and setting which results from it is forward, since the motion is in the direction of the sequence of the signs. The second motion of the ecliptic results from the rotation of its pole, which produces a wobbling effect. As a result of this wobbling the whole plane of the ecliptic moves back and forth. When the pole of the ecliptic moves from position (1) to position (2) (figure 76), the western part of the ecliptic moves up, and rises above the horizon, whereas the eastern part moves down and sets. Now since this motion is in the direction of the sequence of the signs, the rising and setting at position (2) is forward. As the pole of ecliptic moves from position (2) to (3), however, the plane of the ecliptic wobbles back from the east to the west, that is in the direction opposite the sequence of the signs. Therefore, the rising and setting is backwards, which means that the end of the sign rises or sets before its beginning.

The rising and setting of the rest of the signs follows a similar pattern, and as the pole of the ecliptic moves from positions (2) to (3), and then to (4), the four signs which have a forward rising set backwards, whereas the four signs which have a forward setting rise backwards.

[32]-[33] Figure 79 illustrates this last case. Here the latitude of the locality is equal to 90°. The zenith and the north pole coincide, and thus the declination circles, which are perpendicular to the equator, and the altitude circles, which are perpendicular to the horizon, also coincide.

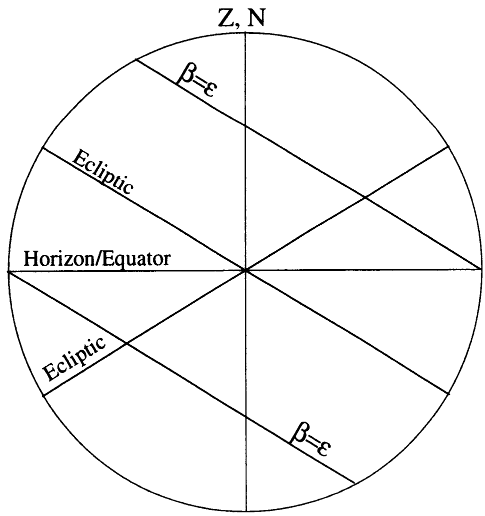


FIGURE 79

It is clear from this figure that any day circle drawn parallel to the equator is also parallel to the horizon. Half the ecliptic is then permanently visible, while the other half is invisible. Now since the sun has a slower motion in the apogee part of the ecliptic, therefore, it stays longer in that half, and the duration of day light is longer than the duration of the night. Ṣadr gives a difference of 9 days between these two sections, producing a daylight of 187 days, and a night of 178 days. This is in disagreement with the seven days difference given in the *Tadhkira* and the *Tuḥfa* (see *Tadhkira*, p. 281, and *Tuḥfa*, f. 234r).

[34] Dawn and twilight are functions of the depression of the sun below the horizon (see below, the chapter on dawn and twilight). When the latitude of the locality is 90°, this depression is a function of the motion of the sun on the ecliptic. Ṣadr indicates that as long as the sun is within a depression arc of 18° below the horizon, the twilight, or the dawn, are visible. By using the sine rule, we can solve for the longitude of the sun corresponding to this latitude, and this, according to Ṣadr, and also using accurate calculation, comes out to be 50°, which is almost equal to 50 days.

[35]-[36] It is clear from figure 79 that the rotation of a star parallel to the equator, that is, its first motion, is parallel to the horizon, and therefore causes no rising or setting of the star. The second motion of the star, however, is parallel to the ecliptic, and the path of the star during this motion will intersect the horizon if the latitude of the locality is less than the obliquity of the ecliptic. In this case the star rises and sets, whereas it is permanently visible, or invisible, if the latitude of the locality is equal to, or greater than the above obliquity.

Finally, if a star has no latitude, then it lies on the ecliptic, and half its path is visible, while the other half is not.

CHAPTER 15

[1] Ptolemy briefly discusses the risings, culminations, and settings of the fixed stars in Book VIII of the *Almagest* (see *Almagest*, VIII, pp. 410-413). The corresponding chapters in the later works are more elaborate and include detailed description of this theory (for the corresponding sections see *Tadhkira*, pp. 283-7, and *Tuḥfa*, f. 237v-239v).

[2] Figure 80 illustrates the definitions in this paragraph: arc *VB* of the ecliptic is the arc of equal degrees, while arc *VA* is the corresponding oblique ascension of these degree.

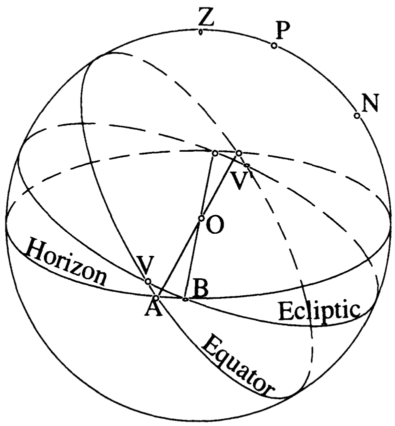


FIGURE 80

For any locality on the terrestrial equator, the celestial equator is perpendicular to the horizon. Figure 81 shows the initial position where the longitude of point *V* is zero. When *V* moves through a quadrature (figure 82), it coincides with the zenith *Z* of the locality, and both the pole of the equator *N*, and the pole of the ecliptic *P* fall on the horizon. In this case the degree of the ecliptic *VB*, and its ascension *VA*, are both equal to 90°.

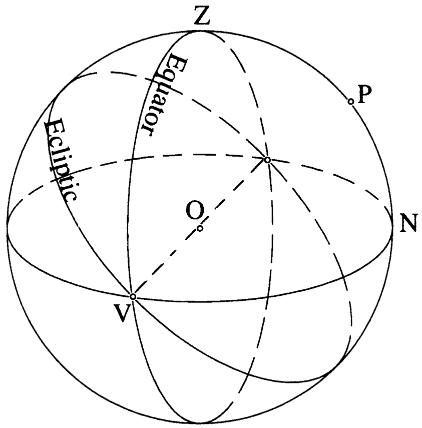


FIGURE 81

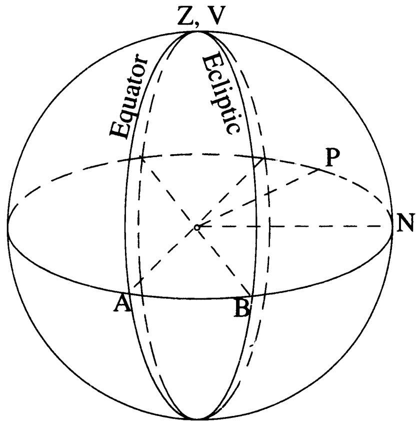


FIGURE 82

[3]-[5] If, in the above case, the vernal equinox moves through less than a quadrature (figure 83), then $VB > VA$, and $90 - VB < 90 - VA$. The remaining part of the ecliptic is then symmetrical with the first part, and the relation between the degree of the ecliptic and its ascension follows accordingly.

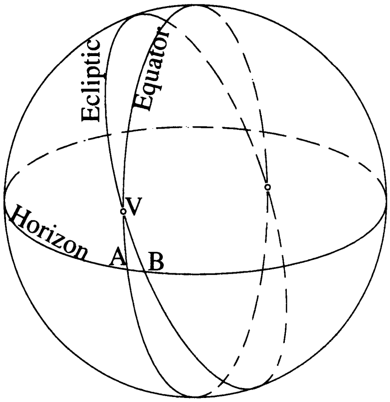


FIGURE 83

Now since the degree of the ecliptic is greater than its ascension on either side of the equinoxes, then as long as this degree is less than a quadrature, therefore, the sum of the degrees is greater than the sum of the ascensions. The degrees of the ecliptic of a quadrature which incorporates an equinoctial point are thus greater than the corresponding ascension. The reverse is true for a quadrature which incorporates a solstice.

[6] For a locality on the equator, the meridian is perpendicular to the equator, and so is the horizon. The meridian is thus one of the horizons of the equator. This means that the culminations of the ecliptic and the equator are similar to the ascensions of both through the horizon. Similarly, a declination circle is perpendicular to the equator, and it may thus be one of the horizons of the equator. Therefore, the transits of the ecliptic and equator through a declination circle are similar to the ascensions of both through the horizon.

[7] It is clear from figure 80 that as point V rotates from one side of the horizon to the other, the degree of the ecliptic and its corresponding ascension on the equator will both be equal to 180°. Moreover, when VB is on the side of the visible pole N of the world, then $VB > VA$, and $180 - VB < 180 - VA$. If, however, the ecliptic moves with respect to the equator such that VB is on the side of the invisible pole of the world, then the degree of the ecliptic is less than its ascension, and the remaining part of half the ecliptic is greater than its ascension.

[8]-[12] These paragraphs are respectively illustrated in figures 84, 85, 86, and 87, and are clearly explained and proved in the text itself.

[13] To illustrate this paragraph consider figures 88 and 89: in the first figure, as a star crosses point V it falls on the side of the pole N with respect

to the equator. It is clear that in this first case the degree of the ecliptic is greater than its ascension ($VB > VA$). The mid point of the other half of the ecliptic is point V' which is diametrically opposite to point V (figure 89). The position of the ecliptic with respect to the equator in this second half flips, such that as a star crosses point V' it falls on the side of the invisible pole D of the world. It is clear from figure 89 that the degree of the ecliptic in this case is less than its ascension ($V'B' < V'A'$).

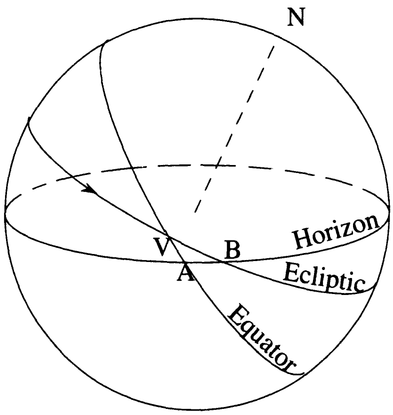


FIGURE 88

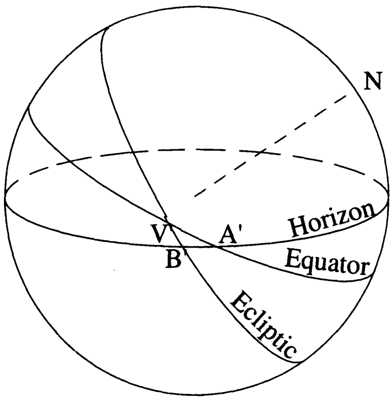


FIGURE 89

[14]-[15] For a discussion of these paragraphs see chapter 14 above.

[16] A star which has no latitude is on the ecliptic, and its degree on the ecliptic coincides with it. Such a star culminates with its degree.

Figure 90 shows a star *S* which has a latitude, in the case when the pole *P* of the ecliptic falls on the meridian circle. Let the culmination point of *S* be *S′* on the meridian. Now if we draw the latitude circle from *P* through *S′*, then this circle coincides with the meridian. The meridian is thus perpendicular to the ecliptic, and intersects it at point *X*, the degree of the ecliptic. Therefore, the degree of the star, and the star itself culminate simultaneously.

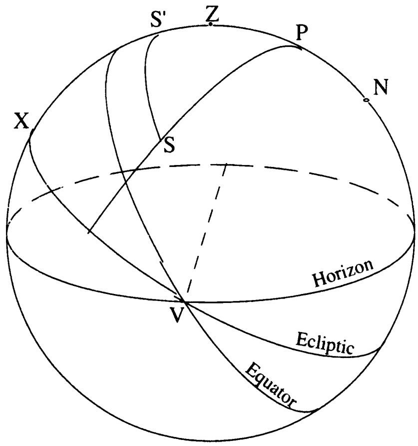


FIGURE 90

In figure 91 the pole of the ecliptic is west of the meridian. The equal degrees of the star is *VX*, point *X* being the intersection between the ecliptic and the latitude circle drawn from *P* through *S*. The transit of the star is the point of the ecliptic which culminates simultaneously with *S*; let this be point *Y*. Point *Y* should therefore fall on the same declination circle *NSY* which passes through the star *S*. Now it is clear from figure 91 that *VY*, the degree of transit of the star, is greater than *VX*, the degree of the star, and that the star culminates before its degree.

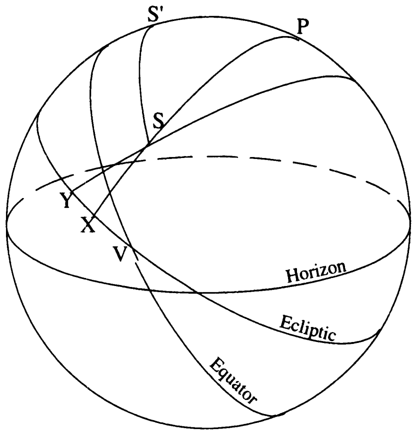


FIGURE 91

[17] As long as the pole of the ecliptic falls north of the meridian, the southern signs, that is the signs between, and including, Libra and Pisces, ascend (for an illustration see chapter 14 above). Therefore, the signs between, and including, Sagittarius and Cancer culminate during this period.

The culmination of signs at different positions of the pole of the ecliptic similarly follow.

[18]-[21] For localities on the equator, the ascension and descension of stars, like those of the ecliptic, are similar to the culmination. For these localities, a star ascends simultaneously with its declination circle. Therefore, when the pole of the ecliptic is on the horizon, this horizon coincides with both the declination circle, and the latitude circle, where the degree of ascension and the degree of the star are respectively marked. The star and its degree thus ascend at the same time.

If the pole of the ecliptic does not fall on the horizon, then the results of the present paragraphs may be obtained by using an analysis similar to that used for the transits.

[22] In figure 92, the degree of the sun is point S, while the point symmetrical to it is point S'. The degree of ascension of the star is point P, and it is the degree of the ecliptic which ascends simultaneously with the star. If P is between S and S', then the star rises after the sun, and its ascension occurs during daylight. If P is between S' and S, then the planet ascends during the night.

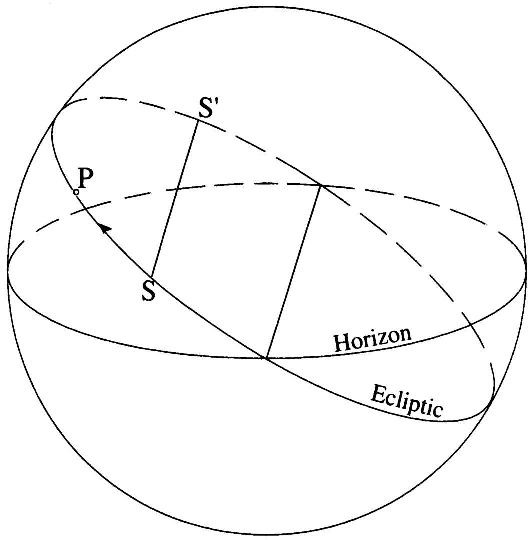


FIGURE 92

CHAPTER 16

[1] In the *Almagest*, there is no chapter devoted to time reckoning, although parts of Book II have some bearing on this question, namely the sections on rising times and oblique ascensions (see *Almagest*, II, pp. 90-104; also for a discussion of time reckoning in the *Almagest* see HAMA, pp. 40-43, and Pedersen, pp. 114, 124-125). On the other hand, separate chapters on time reckoning do exist in similar earlier Arabic sources (for the corresponding, but different chapters see *Tadhkira*, p. 299-303, and *Tuḥfa*, f. 248v-258r).

[2]-[5] Since, during its yearly motion, the sun moves on a deferent which is eccentric with respect to the center of the earth, therefore its speed varies from a maximum at perigee, to a minimum at the apogee of the ecliptic. Also, during its daily rotation along a circle which is parallel to the equator, the sun does not return to its starting point on the ecliptic, but to a point which is slightly displaced with respect to the first position. This displacement results from the motion of the sun along the ecliptic, and it has a mean value of 0;59° per day. As a result, the sun rises from a different point on the horizon, such that the difference between the ascensions of any two arcs through which the sun moves at any two points in time, is equal to the ascension of the arc of the ecliptic covered by the sun between these two points.

It is clear that the motion of the sun varies as a result of the variation of its speed on the ecliptic, as well as the variation of its ascensions.

Now, a mean day is posited, namely the time taken by the sun to return, after its daily rotation, to a point on the meridian. To obtain the full arc of motion of the sun during such a rotation, however, an additional arc should still be added, and this is the mean motion of the sun along the ecliptic in one day. The reason the meridian is chosen as the reference point is that the meridian is one of the horizons of the terrestrial equator. This means that, at any locality, the degree of the ecliptic, and the degree of transit always differ by a fixed value, whereas ascensions differ for various degrees.

The variation of the speed of the sun along the eccentric deferent increases in one half of its path, and decreases in the other half. The ascensions of the different arcs of the ecliptic, on the other hand, are accumulative, and alternate from additive to subtractive every quadrant (see the chapter on ascensions above). Now, since the quadrants where the motion of the sun increases or decreases, do not coincide with the quadrants where ascensions increase or decrease, the compounded effect of the above two variations, depends upon the relative positions of the different quadrants with respect to each other, as clearly illustrated in these paragraphs.

Ṣadr also discusses here the equatorial degrees of time, and the corresponding equal hours, as opposed to the temporal or unequal ones. Ṣadr mentions that in reality an equal hour is not 15 (time) degrees, but rather 15 plus a fraction which corresponds to the motion of the sun along the ecliptic during one hour. This will be the mean daily motion of the sun along the ecliptic, i.e. 0;59°, divided by 24, which is approximately equal to 0;2,30°.

[6]-[8] These two paragraphs briefly, but clearly, discuss some of the different systems for determining months and years. The sections are self explanatory and require no further elaboration.

CHAPTER 17

[1] The discussion of dawn and twilight is unique to the Islamic tradition, and is one of the cases where existing astronomical principles are applied to the solution of a problem of specific cultural significance, namely the problem of finding the times of the morning and evening prayers (for the corresponding sections see *Tadhkira*, pp. 295-9, and *Tuḥfa*, f. 243v-248v; also for a discussion of the related problems of the duration of dawn and twilight, and the height of the atmosphere see respectively, Kennedy, 1983, pp. 284-292, and King and Saliba, pp. 445-466).

[2]-[4] Ṣadr sets out to explain in these paragraphs when and why dawn becomes visible for an observer at point *O*. Ṣadr's descriptive explanation is not always clear; to illustrate his approach consider figure 93: circle *ZHKS* is an azimuth circle which passes through the center *S* of the sun. The plane of this circle also passes through the center *E* of the earth. Points falling inside triangle *ABG* are dark, and hence not visible, since they fall within the shadow cone of the earth. Now, the atmosphere reflects some of the light of the earth, and as a result of this reflection parts of the atmosphere are illuminated before the sun actually crosses above the horizon of the locality. Also the atmosphere has variable density, and the closer it is to the surface of the earth, the denser it becomes. Ṣadr, like his predecessors before him, maintains that only dense air reflects the light of the sun, and therefore, the rays should be close enough to be seen by point *O*. This means that the upper side *BA* of the shadow cone should intersect the real horizon *NOM* at a close enough point *M*, which marks the beginning of dawn. This point is found by observation to correspond to a depression of the sun of around 18° below the horizon (for the corresponding 18° figure see *Tadhkira*, p. 297, and *Tuḥfa*, f. 243v).

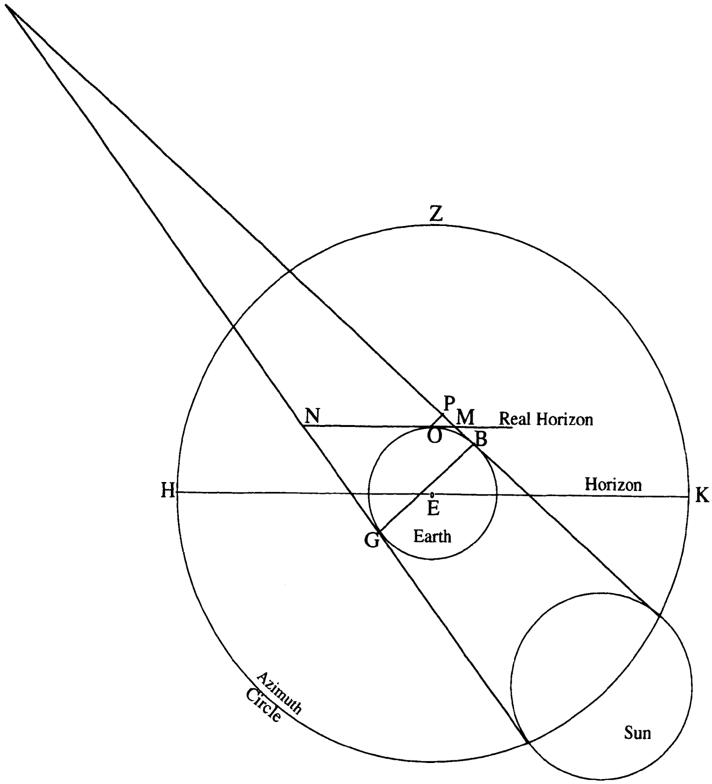


FIGURE 93

Ṣadr also maintains that point P is closer to the observer at O than M, hence visible at O when M is not. That, according to Ṣadr, may explain false dawn.

To explain true dawn, Ṣadr has to assume that stronger light overcomes the vapor effect and makes point M itself visible, but P more so.

[5]-[6] In these paragraphs, Ṣadr discusses the duration of dawn and twilight at different localities. For a locality at the equator, for example, and when the sun is at one of the equinoctial points, the dawn lasts for an hour and a fifth. This is true because, at the above locality, the equator is perpendicular to the horizon, and it is thus an altitude circle; and since the depression of the sun when it first starts to illuminate the atmosphere is 18° measured on this same altitude circle, the time taken for the sun to rise above the horizon is 18° ÷ 15°/hour, which is one hour and a fifth.

(For further discussion of the duration of dawn and twilight see Kennedy, 1983, pp. 284-292.)

CHAPTER 18

[1] This chapter deals with two problems: the first is finding the local meridian, and is a simple problem of general mathematical interest. The second is finding the direction of the *qibla*. Clearly, this second problem is a distinctly Islamic one that had engaged many Muslim astronomers over the years. Many methods were developed to solve this problem of spherical trigonometry, some of which were approximate, while others were accurate. Whether approximate or precise, however, one expects some discussion of the problem to appear in general astronomical handbooks similar to Ṣadr's (for the corresponding chapters see *Tadhkira*, pp. 307-9, and *Tuḥfa*, f. 262r-265v; on methods for finding the local meridian see for example, Kennedy, 1983, pp. 613-617; on methods for finding the azimuth of the *qibla* see for example, king, 1975, king, 1979, and Berggren).

[2]-[4] These paragraphs discuss two different methods for leveling the ground. Figures 94 and 95 are sketches of the two instruments which are used in this leveling. The discussion is simple and does not require further elaboration.

[5] Figure 96 illustrates this paragraph; the two positions of the sun are P and P', and their altitudes above the plane of the horizon are equal. The shadow cast by the spike or gnomon when the sun is at point P intersects the circle at R, while the shadow cast when the sun is at P' intersects the circle at Q. It is easy to show that line QR is parallel to the east-west line, and therefore, the local meridian, or the meridian line, is along the line connecting the midpoint of arc QR to the center O of the circle.

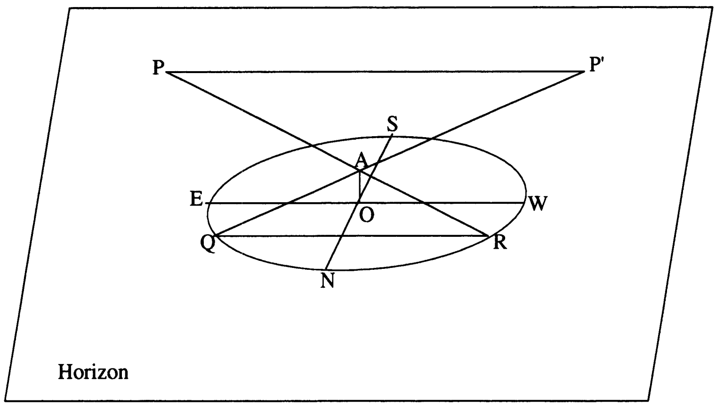


FIGURE 96

[6] The alternative method proposed in this paragraph is equivalent to the first one, because the altitude of the sun is the same for the two equal shadows. On the other hand, the optimal speed of growth of the shadow is when the length of the gnomon is half the radius of the circle. Therefore, when the shadow enters or exists the circle, it is double the size of the gnomon. Around this ratio, the speed of growth of the shadow is fast enough, but not too fast to locate.

[7]-[9] The discussion in these paragraphs has no equivalent in the *Tadhkira*, and its parallel in the *Tuḥfa* is much shorter (see *Tuḥfa*, f. 263v-264r). Other works on finding the local meridian, such as a similar, but more elaborate method discussed by the eleventh century scholar Bīrūnī, take note of the approximation involved in the above method which does not account for the proper motion of the sun, and indicate that the variation resulting from this error is minimal around solstice (see Kennedy, 1983, p. 617).

In figure 97, the midday altitude *QM* is determined by the intersection of the day circle *SM* with the meridian circle. *QM* is equal to the altitude *QB* of the equator minus the declination *BM* of the sun for that day. When the ecliptic is on the other side of the equator, the declination is added rather than subtracted. It is clear therefore, that the midday altitude is a function of the declination of the sun. Now as the sun moves along the ecliptic, the declination changes, and his change is minimal when the sun is closer to the solstice.

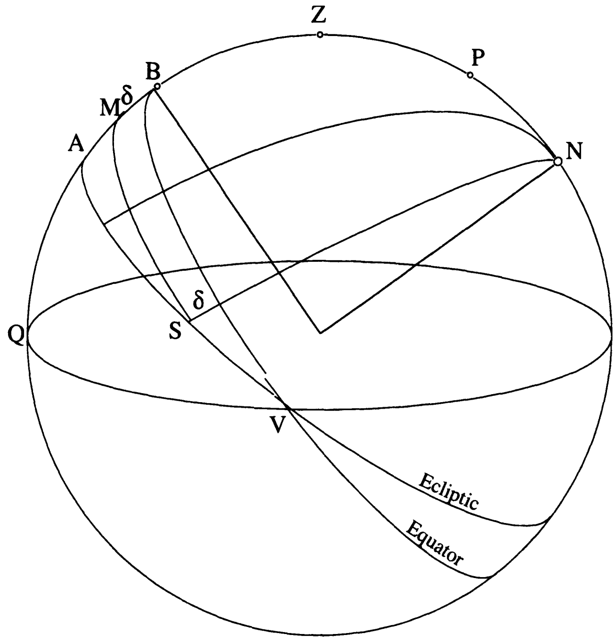


FIGURE 97

To illustrate this last point, Ṣadr calculates the change in declination during one day of motion of the sun away from the equinox, and then he calculates the change during three days' motion of the sun away from the solstice. The results are fairly accurate, and clearly indicate the advantage of finding the local meridian when the sun is near the solstice.

[10]-[13] These paragraphs discuss some simple and approximate methods for finding the direction of the *qibla*.

The first two cases are easy special cases in which Mecca, and the locality in consideration have either the same longitude or the same latitude, and the direction of Mecca is as described in the paragraphs.

The first method for finding the direction of Mecca in the general case when the latitudes and longitudes are different, is an approximation which was frequently used by Muslim astronomers. A discussion of this method can be found in King, 1979.

The second method which employs the astrolabe proceeds by placing the solar position at the meridian line of the astrolabe, that is, along the circle which passes through the zenith of the locality. This point is then moved through an angle equal to the difference in longitudes between Mecca and the locality, at which point the corresponding altitude of the sun is found. Now, given that the solar position in question is the point of the ecliptic at

which the daily circle of the sun passes through the zenith of Mecca, the eastern altitude of the sun at that position is, therefore, equal to the altitude of the zenith of Mecca above the horizon of the locality. The equal western altitude of the sun casts a shadow in the plane of the great circle passing through the zenith of the locality and the zenith of Mecca. Hence it points in the direction of the *qibla*.

Finally, the latitudes and longitudes of Mecca given By Ṣadr are similar to the ones given in the *Tadhkira* (p. 307-9) and the *Tuḥfa* (f. 264v) (on geographical coordinates of localities in Islamic sources see Kennedy, 1987, especially p. 226 for the coordinates of Mecca, and pp. 82-83 for those of Bukhārā; it should be noted that none of those sources gives the exact coordinates used by Ṣadr). Moreover, at 7° of Cancer, or 23° of Gemini, the longitude of the sun away from an equinoctial point is 67°. Thus, for an obliquity of the ecliptic of 23;35°, the declination of the sun for the above longitude is 21;36°, as opposed to 21;40° given by Ṣadr.

BIBLIOGRAPHY

Abbud, Fuad. "The Planetary Theory of Ibn al-Shāṭir: Reduction of the Geometric Models to Numerical Tables." *Isis* 53 (1962): 492-9.

Ahlwardt, W. *Die Handschriften-Verzeichnisse der koniglichen Bibliothek zu Berlin: Verzeichniss der arabischen Handschriften.* Berlin: A. Asher & Co., 1982.

Almagest: Ptolemy. *Ptolemy's Almagest.*Trans. G.J. Toomer. New York: Springer-Verlag, 1984.

Aristotle. *On the Heavens.* Trans.W.K.C. Guthrie. Cambridge: Harvard University Press, 1986. Vol. VI.

Barthold, W. *An Historical Geography of Iran.* Trans. Svat Soucek. Princeton: Princeton University Press, 1984.

Berggren, J.L. "A Comparison of Four Analemmas for Determining the Azimath of the Qibla." *Journal for the History of Arabic Science* 4 (1980): 69-80.

Al-Bīrūnī, Abū Rayḥān. *Al-Bīrūnī: The Exhaustive Treatise on Shadows.* Trans. with Intro. by E.S. Kennedy. 2 vols. Aleppo, Syria: Institute for the History of Arabic Science, 1976.

Al-Biṭrūjī. *Kitāb fī- al-Hay'ah, Al-Biṭrūjī: On the Principles of Astronomy.* Trans. Bernard R. Goldstein. 2 vols. New Haven: Yale University Press, 1971.

Brockelmann, C. *Geschichte der arabischen Litteratur.* Vol. 2, Suppl. 2. Leiden: E.J. Brill, 1937.

Catalogus Codicum Manuscriptorum Orientalium qui in Museo Britannico Asservantur. Part 2. Cod. Arab. Amplect. London: impensis Curatorum Musei brittanici, 1846-71.

Dallal, Ahmad. "Al-Bīrūnī On Climates." *Archives Internationale D'Histoire Des Sciences* 34.112 (1984): 3-18.

De Vaux, Carra. "Les spheres celestes selon Nasīr-Eddīn Attūsī." *Recherches sur l'histoire de l'astronomie ancienne.* Ed. Paul Tannery. Appendix VI. Paris: Gauthier-Villars & fils, 1893. 337-361.

Dreyer, J.L.E. *A History of Astronomy from Thales to Kepler.* New York: Dover Publications, Inc., 1953.

Al-Dujaylī, 'Abd al-Ṣāḥib 'Imrān. *A'lām al-'Arab fī al-'Ulūm wal-Funūn.* 2 vols. Baghdad: Maṭba'at al-Nu'mān, 1966.

Euclid. *The Thirteen Books of Euclid's Elements.* Trans. with Intro. and Comm. by Sir Thomas L. Heath. 3 vols. New York: Dover Publications, Inc.

Flugel, Gustav. *Die Arabischen, Persischen und Turkischen Handschriften Der Kaiserlich-Koniglichen Hofbibliothek Zu Wien.* Wien: Druck und Verlag der K.K. Hof und Staatsdruckerei, 1865.

Goldstein, Bernard R. "The Arabic Version of Ptolemy's Planetary Hypothesis." *Transactions of the American Philosophical Society.* Vol. 57, Part 4. Philadelphia: The American Philosophical Society, 1967.

Ḥājī Khalīfa, Kātib Jelebī. *Kashf al-Ẓunūn 'an Asāmī al-Kutub wa al-Funūn.* Ed. Gustav Flügel. 16 vols. London: Oriental Translation Fund, 1852.

HAMA: Neugebauer, Otto. *A History of Ancient Mathematical Astronomy.* New York: Springen-Verlag, 1975.

Hartner, Willy. "Naṣīr al-Dīn al-Ṭūsī's Lunar Theory." *Physics* II (1969): 287-304.

———. "Copernicus, the Man, the Work, and its History." *Proceedings of the American Philosophical Society*. Philadelphia: The American Philosophical Society, 1973. 413-552.

Hodgson, Marshall G.S. *The Venture of Islam*. 3 vols. Chicago: The University of Chicago Press, 1974.

Ibn al-Haytham. *Al-Shukūk 'Alā Baṭlamyūs*. Ed. A. Sabra and N. Shehabi. Cairo: Dar al-Kutub, 1971.

Ibn Baṭūṭa. *Voyages d'Ibn Batoutah*. Trans. C. Defrémery and B.R. Sanguinetti. 3 vols. Paris: Imprimerie nationale, 1977.

Ibn Kuṭlūbughā, Zein-ad-dīn Kāsim. *Tāj al-Tarājim fī Ṭabaqāt al-Ḥanafiyya*. Ed. Gustav Flügel. Leipzig: F.A. Brockhaus, 1862.

Kaḥḥāla, Umar Riḍā. *Mu'jam al-Mu'allifīn*. 2 vols. Damascus: al-Maktaba al-'Arabiyya, 1958.

Karatay, Fehmi Edhem. *Topkapi Sarayi Muzesi Kutuphanesi Arapca Yazmalar Katalogu*. 4 vols. Istanbul: Topkapi Sarayi Muzesi, 1962-9. Vol 3.

Kennedy, E.S. "A Survey of Islamic Astronomical Tables." *Transactions of the American Philosophical Society*. Vol. 46, Part 2. Philadelphia: The American Philosophical Society, 1956. 122-177.

———, and I.Ghanem. *The Life and Work of Ibn al-Shāṭir*. Aleppo, Syria: Institute for the History of Arabic Science, 1976.

———, colleagues and former students. *Studies in the Islamic Exact Sciences*. Ed. David King and Mary Helen Kennedy. Beirut: American University of Beirut, 1983.

———, and M.H. Kennedy. *Geographical Coordinates of Localities From Islamic Sources*. Frankfurt: Institut fur Geschichte der Arabisch-Islamischen Wissenschaften, 1987.

King, David. "Al-Khalīlī's Qibla Table." *Journal of Near Eastern Studies* 34.2 (1975): 81-122.

———. "Kibla." *Encylopedia of Islam*. 2nd Edition. Leiden: E.J. Brill, 1979. Vol. 3. 83-88.

———, and George Saliba, eds. *From Deferent to Equant: A Volume of Studies in the History of Science in the Ancient and Medieval Near East in Honor of E.S. Kennedy*. New York: The New York Academy of Sciences, 1987.

Al-Khowarezmi, Al-Kātib. *Liber Mafātīh al-Olūm*. Ed. G. Van Vloten. Brill: Luguni-Batavorum, 1895.

Kunitzsch, Paul. *Arabische Sternnamen in Europa*. Wiesbaden: Otto Harrassowitz, 1959.

Livingston, J. "Naṣīr al-Dīn al-Ṭūsī's *al-Tadhkira*: a Category of Islamic Astronomical Literature." *Centaurus* 17 (1973): 260-275.

Loth, Otto. *A Catalogue of the Arabic Manuscripts in the Library of the India Office*. London: Secretary of State for India, 1877.

Al-Luknawī, 'Abd al-Ḥayy. *Al-Fawā'id al- Bahiyya fī Tarājim al-Ḥanafiyya*. Banaras, India: Maktabat Nadwat al-Ma'ārif, 1967.

Madelung, Wilferd. *Religious Trends in Early Islamic Iran*. Columbia Lectures on Iranian Studies, 4. New York: Bibliotheca Persia, 1988.

Minorsky, V. *Ḥudūd al-'Ālam*. London: Messrs. Luzac & Co. Ltd., 1970.

Morelon, Regis. *Thābit Ibn Qurra: oeuvres d'astronomie*. Paris: Societe d'edition "Les Belles Lettres," 1987.

Morgan, David. *Medieval Persia: 1040-1797*. London: Longman, 1988.

Neugebauer, Otto. "Thābit ben Qurra 'On the Solar Year' and 'On the Motion of the Eighth Sphere.'" *Proceedings of the American Philosophical Society*. Vol. 106, no. 3. Philadelphia: American Philosophical Society, 1962.

——. *The Exact Sciences in Antiquity*. New York: Dover Publications, Inc., 1969.

——. *Astronomy and History: Selected Essays*. New York: Springer-Verlag, 1983.

Nihāya: Al-Shīrāzī, Quṭb al-Dīn. *Nihāyat al- Idrāk fī Dirāyat al-Aflāk*. Istanbul: Koprulu, MS # 657.

Pedersen, Olaf. *A Survey of the Almagest*. Denmark: Odense University Press, 1974.

Pingree, David. *The Zīj al-'Alā'ī. The Astronomical Works of Gregory Chioniades*. Amsterdam: J.C. Gieben, 1985. Vol. 1.

Qānūn: Ibn Sina, Abū Alī al-Husain 'Abdullah. *Al-Qānūn fīl-Ṭibb*. New Delhi: Vikas, 1982.

Qur'ān: *The Holy Qur'ān*. Trans. with Comm. by A. Yusuf Ali. The United States: The Muslim Students' Association, 1975.

Sabra, A.I. "Psychology Versus Mathematics: Ptolemy and Alhazan on the Moon Illusion." *Mathematics and its Applications to Science and Natural Philosophy in the Middle Ages: Essays in Honor of Marshall Clagett*. Eds. Edward Grant and John E. Murdoch. New York: Cambridge University Press, (1987). 217-247.

Saliba, George. "The First Ptolomaic Astronomy at the Maraghah School." *Isis* 70.254 (1979): 571-6.

——. "The Original Source of Quṭb al-Dīn al-Shīrāzī's Planetary Model." *Journal for the History of Arabic Science* 3.1 (1979): 3-18.

——. "Falakī min Dimashk Yarud 'alā Hay'at Batlamyūs." *Journal for the History of Arabic Science* 4 (1980): 3-17.

——. "Arabic Astronomy and Copernicus." *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 1 (1981): 73-87.

——. "The Role of the Almagest Commentaries in Medieval Arabic Astronomy: A Preliminary Survey of Ṭūsī's Redaction of Ptolemy's Almagest." *Archives Internationales D'Histoire Des Sciences* 37.118 (1987): 3-20.

——. "A Medieval Arabic Reform of the Ptolemaic Lunar Model." *Journal for the History of Astronomy* XX (1989): 157-164.

——. *The Astronomical Work of Mu'ayyad al- Dīn al-'Urḍī: A Thirteenth Century Reform of Ptolemaic Astronomy. Kitāb al-Hay'ah*. Ed. with Intro. by George Saliba. Beirut: Markaz Dirāsāt al-Wiḥda al-'Arabiyya, 1990.

——, and E. S. Kennedy. "The Spherical Case of the Ṭūsī Couple." *Arabic Science and Philosophy* 1.2 (1991): 285-91.

——. "Islamic Planetary Theories After the Eleventh Century A.D." To Appear.

Sarkīs, Yūsuf Ilyās. *Mu'jam al-Maṭbū'āt al-'Arabiyya wal-Mu'arraba*. Cairo: Maṭba'at Sarkīs, 1928.

Sayili, Aydin. *The Observatory in Islam*. Ankara: Türk Tarih Kurumu Basimevi, 1960.

Sezgin, Fuat. *Geschichte des arabischen Schrifttums: Astronomie*. Band 6. Leiden: E.J. Brill, 1978.

Shapin, Steven. "History of Science and Its Sociological Reconstructions." *History of Science* XX (1982): 157-211.

Shifā': Ibn Sīna. Al-Shifā': Al-Ṭabī'īyāt. Vol. 2, Parts 2-4. Ed. Maḥmūd Qāsim. Cairo: 1969. Vol. 2, Part 5. Ed. Muntaṣir et.al. Cairo: al-Maṭba'a al-Amīriyya, 1965.

Souissi, Mohamed. *La langue des mathematiques en arabe*. Tunis: L'Imprimerie Officielle, 1968.

Strange, G. Le. *The Lands of the Eastern Caliphate*. London: Frank Caus & Co. Ltd., 1966.

Suter, Heinrich. *Die Mahtematiker Und Astronomen Der Araber Und Ihre Werke*. Leipzig: B.G. Teubner, 1900.

Swerdlow, N.M., and O. Neugebauer. *Mathematical Astronomy In Copernicus's De Revolutionibus*. Parts 1 & 2. New York: Springer-Verlag, 1984.

Tadhkira: Rageb, F. J. *Naṣīr al-Dīn al-Ṭūsī's Memoir on Astronomy (al-Tadhkira fī 'ilm al-hay'a)*. 2 vols. New York: Springer-Verlag, 1993.

Al-Tahānawī, Muḥammad A'la ibn 'Alī. *Kashshāf Muṣṭalaḥāt al-Funūn*. 6 vols. Beirut: Khayats, 1966.

Ṭāshkoprūzāde, Aḥmad b. Muṣṭafā. *Miftāḥ al-Sa'āda wa Miṣbāḥ al-Siyāda*. 3 vols. Cairo: Dār al-Kutub al-Ḥadītha, 1968.

Ṭlās, Muḥammad As'ad. *Al-Kashshāf 'an Khazā'in Kutub al-Awqāf*. Baghdad: 1953.

Tuḥfa: Al-Shīrāzī, Quṭb al-Dīn. *Al-Tuḥfa al- Shahiyya*. Muṣil, Jami' al-Bāshā, MS 287.

Al-Zirkalī, Khayr al-Dīn. *Al-A'lām*. Beirut: Dār al-Kutub lil-Malāyīn, 1969.

Zaydān, Jurjī. *Tārīkh Ādāb al-Lugha al-'Arabiyya*. 3 vols. Cairo: Maṭba'at al-Ḥilāl, 1913.

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